FINAL REPORT

Field Validation of Visual Cleaning Performance Indicator (VCPI) Technology

ESTCP Project WP-0410

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Environmental Security Technology Certification Program

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14. ABSTRACT

Battelle, in collaboration with engineers at Hill Air Force Base, the Air Force Research Laboratory, and the Naval Surface Warfare Center- Carderock Division have developed and field tested a Visual Cleaning Performance Indicator (VCPI) technology as a means to verify surface cleanliness on aluminum and painted steel alloys. The VCPI technology represents a significantly new, environmentally acceptable method of inspecting and validating the cleaning performance of commercial cleaners and efficiency of large area DoD cleaning operations.

This ESTCP project served to demonstrate the effectiveness and versatility of VCPI, as well as develop DoD end-user support for an inexpensive in-situ cleaning verification method.

15. SUBJECT TERMS

Cleaning verification, Visual Cleaning Performance Indicator, Aircraft cleaning, Ship cleaning

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Acronyms

AF	Air Force
AFB	Air Force Base
AFRL	Air Force Research Laboratory
CFR	Code of Federal Regulations
CIE	Commission Internationale de l'Eclairage
COTS	Commercial Off The Shelf
DEM/VAL	Demonstration/Validation
DI	Deionized
DoD	Department of Defense
ESTCP	Environmental Security Technology Certification Program
EtOH	Ethanol
FG3/FCF	Food Green 3/Fast Green FCF
HAFB	Hill Air Force Base
HECSA	Humphreys Engineer Center Support Activity
HVLP	High Volume Low Pressure
i-PrOH	Isopropanol
MG/L	Milligram/Liter
MIL-PRF	Military Performance
MNS	Mayport Naval Station
NAVAIR	Navy Air Systems Command
NAVSEA	Navy Sea Systems Command
NPDES	National Pollutant Discharge Elimination System
NSTM	Naval Ship's Technical Manual
NSWC	Naval Systems Warfare Center
O&G	Oil and Grease
OO-ALC	Ogden Air Logistics Center
ORO	Oil Red O
P.O.	Process Order
PP	Pollution Prevention
PPE	Personal Protective Equipment
SERDP	Strategic Environmental Research and Development Program
TBD	To Be Determined
T.O	Technical Order
USAF	United States Air Force
USS	United States Ship
UT	Utah
VCPI	Visual Cleaning Performance Indicator
XG	Xanthan Gum

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1. Introduction

1.1 Background

Engineers at the Air Force Research Laboratory (AFRL), the Naval Systems Warfare Center – Carderock Division (NSWC-Carderock), the Ogden Air Logistics Center (OO-ALC), and Battelle have identified and successfully tested in the laboratory and field a Visual Cleaning Performance Indicator (VCPI) technology that is capable of verifying the surface cleanliness of unpainted structures fabricated from aluminum and steel alloys. In concept, the VCPI technology represents an innovative environmentally acceptable method of conducting real-time inspections of contaminated surfaces as well as validating the efficiency of Department of Defense (DoD) large-area cleaning operations.

Traditional Air Force and Navy cleaning requirements and/or specifications for aircraft and ships are referenced in Technical Order (T.O.) 1-1-691, T.O. 1-1-8, as well as the applicable Navy Ships Technical Manual; Chapters 081 and Chapter 631[1,2]. In accordance with these documents, a simple, real-time water break test or visual inspection is normally used as the only measure of cleanliness during large surface cleaning operations. Both inspection methods have limitations due to (1) the nature and chemistry of specific contaminants on the surfaces of structures being cleaned, (2) skill level of production personnel using the technique, (3) lighting and visible access to the more heavily soiled areas, and (4) an inaccurate interpretation of water break results. In response to these limitations, and unscheduled adhesion failures of coatings applied to these contaminated surfaces, a need was identified for a more quantitative real time measure of cleaning efficiency. This need was addressed through a project funded by the Strategic Environmental Research and Development Program (SERDP) Office to develop and demonstrate a cleaning verification tool that offers environmental, technical, and economic advantages over current "depot level" cleaning operations[3]. The results obtained from this investigation, as measured by the Air Force and Navy stakeholders, were positive and supportive of a depot-level process demonstration at Hill Air Force Base (HAFB) and the Mayport Naval Station (MNS).

The intent of the subject Environmental Security Technology Certification Program (ESTCP) project was to build on the previous SERDP efforts and an initial feasibility demonstration that was conducted by Battelle at HAFB. The ESTCP demonstration was designed to assess the effectiveness and versatility of the VCPI technology on aircraft parts, as well as develop support for a suitable military specification and application procedures for the new test and inspection procedures.

For further background and technical guidance, the following documents should be referenced:

- SERDP Project PP-1117 Final Report, from Battelle, entitled "Visual Cleaning Performance Indicators (VCPI) for Cleaning Verification, May 2002. This report can be downloaded directly from the SERDP website, located at http://docs.serdp-estcp.org/index.cfm.

- T.O. 1-1-8, Application and Removal of Organic Coatings for Aerospace and Non-Aerospace Equipment
- T.O. 1-1-691, Aircraft Weapon Systems Cleaning and Corrosion Control
- Naval Ships' Technical Manuals (NSTM), NSTM Chapter 081 "Waterborne Underwater Hull Cleaning of Navy Ships", and NSTM Chapter 631, Volume 2 "Preservation of Ships In-service – Surface Preparation and Painting"

Additional weapon system specific maintenance T.Os and Process Orders (P.Os) identified by the Air Force and Navy served as reference documents for this ESTCP investigation. This document summarizes the results of VCPI technology Demonstration/Validation (Dem/Val) efforts conducted on a single Air Force aircraft and a single Navy ship.

1.2 Objectives of the Demonstration

The primary objective of this program was to support a field-level demonstration and validation of the VCPI technology for verifying the cleanliness of large area surfaces on weapon systems maintained by the Air Force and Navy. If successful, a demonstration of the VCPI technology on test platforms identified at HAFB and the MNS will result in an implementation of the technology into current cleaning operations. The subject technology is intended to provide an improved cleaning processes, reduced maintenance and logistic support costs associated with labor and materials, and an improvement in the performance of corrosion protection systems applied to DoD equipment.

Specific test objectives for the VCPI technology Demonstration/Validation study included:

1. Illustrating the effectiveness of VCPI as an effective way of labeling contaminants on the surfaces of large equipment at two DoD installations: Hill AFB and Mayport Naval Station
2. Receiving end-user feedback that could be used to improve the application and/or detection of VCPI on large area surfaces
3. Determining the operational pros and/or cons, including economics, of long-term use of VCPI by production maintenance facilities

1.3 Regulatory Drivers

Current DoD cleaning operations and discharge limits are regulated by Federal Clean Water Act (ref. 40CFR 433.10). The major maintenance facilities supporting these operations are also required to conform to the discharge limits specified in state issued National Pollutant Discharge Elimination System (NPDES) permits, as well as the control residual oil discharge (i.e., extractant and carrier fluids) limits specific to the respective Air Logistic Centers and Naval

Stations participating in the demonstration. Collectively, these limits are set according to the types and level of cleaning operations conducted at the respective DoD maintenance facilities.

In support of this study, Battelle engineers designed and demonstrated at a single Air Force and at a single Navy maintenance facility an end-item contract deliverable, i.e., a Visual Cleaning Performance Indicator process that complements current cleaning operations. The regulatory drivers for implementing this technology include:

- Meeting Federal Clean Water requirements (per 40 CFR 433) for the direct discharge of chromium. (1.71mg/L on a monthly average basis)
- Meeting local NPDES discharge requirements for chromium (0.3 mg/L on a daily average basis)
- Reducing hydrocarbon and phosphoric acid waste streams
- Controlling residual oil discharge (i.e., extractant and carrier fluids) to a level below the respective Air Logistic Centers and Naval Stations NPDES discharge requirements as measured by oil and grease (10 mg/L on a daily average basis)
- Generating cost savings related to an implementation of VCPI technology sufficient to provide a realistic process specific payback period less than one year

1.4 Stakeholder/End-User Issues

Primary stakeholders for this study included the Air Force and Navy. The stakeholders viewed this demonstration/validation study as a method of providing valuable data and operating experience required to improve the reproducibility of cleaning operations prior to surface preparations. As was outlined in the Demonstration/Validation Plan, a successful implementation of the VCPI technology at DoD and industrial Corrosion Prevention and Control facilities could result in significant savings in maintenance costs due to reduced over cleaning, and reduced corrosion due to improved coating system performance. The results obtained from this study would be used by these stakeholders to accept or reject the VCPI technology.

Each stakeholder agreed to participate in this study to answer the following questions:

1. How does VCPI perform when subjected to real production environments responsible for the overhaul maintenance of ships and aircraft, as well as each weapon systems associated surface contamination?
2. Does VCPI pose any unforeseen operational difficulties during application of the technology (i.e., is the technology user-friendly)?
3. While VCPI is environmentally friendly, does the large-scale use of it in the field pose any unforeseen issues?

According to discussions with the stakeholders, positive answers to each of these questions would accelerate an implementation of the VCPI technology for global DoD use.

2. Technology Description

2.1 Technology Development and Application

VCPI is a dye-containing solution that was developed to indicate where a specific contaminant is on the surface(s) of a piece of equipment. Commercial-Off-The-Shelf (COTS) food grade dyes and coupling agents were selected that preferentially adhere to the contaminants of interest (i.e., for this study - soluble sea salt and hydrophobic soils) (see Figure 1).[4,5,6,7,8] For this ESTCP investigation, two different contaminants required two different dyes for labeling in a real-time production environment. Once the VCPI solution comes into contact with the contaminant of interest, it begins to selectively adhere to the contaminant. In principle, a simple rinse operation reveals the clean areas from the contaminated areas. Contaminated areas on the surfaces of the panels or parts are selectively labeled with the respective VCPI dye that is then removed during the normal cleaning operations. This labeling process allows the operator to focus their cleaning efforts and materials on only those areas that are truly contaminated and provides them with a visual indication of when the substrate is clean (see Figures 2 and 3).

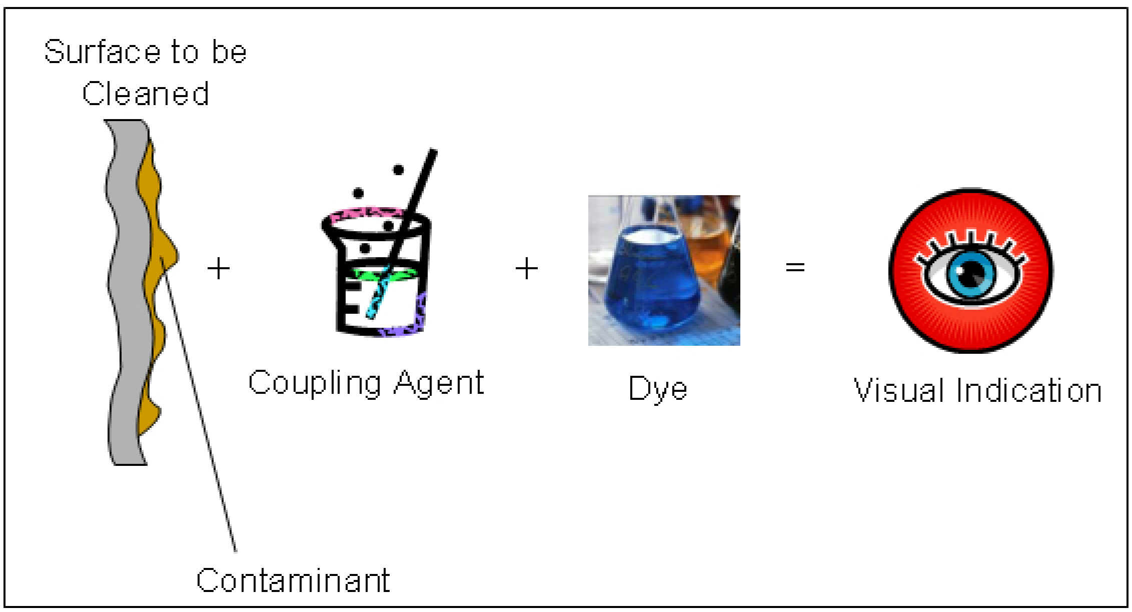

Figure 1. VCPI Technology Process

Figure 2. VCPI Application to Soiled Test Panel during SERDP Evaluation

Figure 3. Visually-indicated Contamination after Solvent Rinsing

For this demonstration, the team spray applied a dilute water/VCPI dye solution to suspected contamination found on the lower wing surfaces of an A-10 aircraft at HAFB, as well as the forward hull surfaces of Navy frigate (i.e., USS Halyburton) at the MNS (see Figures 4 and 5).

Figure 4. Photograph of A-10 Demonstration Aircraft

Figure 5. Photograph of Navy Demonstration Ship

2.2 Previous Testing of the Technology

This ESTCP project evolved from work completed during a SERDP project, HECSA Contract No. 72-99-C-0005, Items 0001, 0002, 0003, and 0004. For further information on this project, please refer to the final report, issued by Battelle on 15 March 2002. This report can be downloaded directly from the SERDP website, located at http://docs.serdp-estcp.org/index.cfm. In addition to the referenced SERDP project, a series of process feasibility demonstrations were conducted on aircraft component parts at Hill AFB (*ref*. Task 8 of Contract No. F42620-00-D-0030-0009), and a process optimization study was funded by the Commercial Airplane Division of Boeing. Collectively, the results obtained from testing conducted in each of these studies confirmed that VCPI dyes are safe for the environment, easy to apply, capable of detecting contamination on metallic substrates, user friendly, and non-compromising of the physical (corrosion resistance and coating adhesion) and chemical (non-residue and compatibility) properties of the treated surfaces.[9]

2.3 Factors Affecting Cost and Performance

Specific production-related factors that would detrimentally affect the cost effectiveness, process performance, and implementation worthiness of the VCPI technology include:

1. No significant reductions in the manpower and/or material costs required for pre-paint surface cleaning operations
2. A slight increase in production flow-through cycle for both demonstrations
3. Negligible reductions in manpower and material costs for painting operations
4. An inability to accurately assess any decrease in the frequency of field & depot-level repainting/recoating operations due to reduced coating failures and structural corrosion
5. The demonstrations failed to quantify any significant reductions in manufacturing costs, including manufacturing capital, manpower, and utility requirements

2.4 Advantages and Limitations of the Technology

When compared to the current “water-break” test, several key advantages that were identified for the VCPI technology include:

1. Potential for a reduced repair time, both man-hours and time the aircraft or ship is non-operational or ‘out-of-service’
2. Potential for reduction in maintenance chemicals (paint, cleaners, etc.)
3. Potential for improved cleaning
4. Potential for extended coating performance and service life

Conversely, the following process limitations were identified:

1. Dye release to the environment during application of the VCPI material to the surfaces of ship hull and aircraft airframe structures

2. The concentration of dye and dwell times required to adequately label contaminants
3. Acceptance of this technology by the stakeholders and possibility of use in production cleaning operations

Negative answers to several of the above questions would potentially limit this technology's use in the intended cleaning verification applications.

3. Demonstration Design

3.1 Performance Objectives

The VCPI demonstrations occurred at two different DoD installations or test platforms during a two week time period. As referenced in Table 1, the technology demonstration on the external fuselage of a single A-10 aircraft at HAFB was conducted during the week of May 22, 2006. A similar demonstration on the external hull of a single Navy ship (USS Halyburton - FFG40) stationed at MNS was held during the week of July 25, 2006 (ref. Table 2). The latter Dem/Val test was completed on a forward hull section of the referenced Navy frigate.

Table 1. Demonstration Schedule at Hill AFB, UT

Day	Activity
May 22, 2006	Arrived at A-10 maintenance facility
May 22, 2006	Last minute planning and coordination; set-up of demonstration equipment
May 23, 2006	Field trial conducted on lower sections of single A-10 aircraft
May 24, 2006	Pack-up supplies; conducted debrief with A-10 engineers

Table 2. Demonstration Schedule at Mayport NS, FL

Day	Activity
July 25, 2006	Arrived at Naval ship maintenance facility
July 25, 2006	Last minute planning and coordination; set-up of demonstration equipment
July 26, 2006	First day of field trials
July 27, 2006	Second day of field trials; pack up of equipment
July 28, 2006	Debrief of results to captain, environmental coordinator and inspectors

A summary of specific performance objectives and actual performance results supporting both Dem/Val tests conducted during this study are summarized in Table 3. The documented results confirm a visual labeling of the respective contaminants at both sites; however, for the Dem/Val test at Hill AFB the ORO dye and target contaminant(s) could not easily be removed from specific aircraft structures, end-user clothing, and the floor surrounding the A-10 test aircraft.

Table 3. Process Performance Objectives

Type of Performance Objective	Primary Performance Criteria	Expected Performance (Metric)	Actual Performance
Qualitative	1. VCPI was effective at selectively labeling oil and grease, as well as salt residues on contaminated surfaces. **The contamination was visibly apparent to observers.**	Demonstrated short dwell time and visual detection with varying lighting conditions.	Objective satisfied
Qualitative	2. VCPI was easily removed when the contamination was removed during cleaning operation. **No post-cleaning dye visibly apparent.**	Demonstrated visual reduction in color intensity from initial labeling through cleaning/rinse operations.	Objective not satisfied
Qualitative	3. VCPI was applied at the site of need – either dockside or in a production hanger environment. **Dye evenly dispersed onto substrate surfaces.**	Demonstrated efficient spray mist application.	Objective satisfied

3.2 Selecting Test Sites/Facilities

Site facilities for the respective Dem/Val tests were chosen on the following basis:

1. Availability of test platforms (i.e., ship and aircraft), and application/process equipment
2. Cleaning operations that would benefit from the VCPI technology (i.e., location(s) performing large area cleaning and painting operations as part of a routine maintenance cycle)
3. Ability for the demonstration team to efficiently coordinate with facility personnel

The last factor was considered the most important because the primary stakeholders and participating representatives from both sites were very cooperative during the planning and implementation of the technology demonstrations.

3.3 Test Platform/Facility History/Characteristics & Present Operations

3.3.1 Test Platform No. 1.

Hill AFB or HAFB is located approximately 30 miles north of Salt Lake City, Utah, and provides support and maintenance for the F-16, A-10, C-130, F-22, and F-35 aircraft. The host organization is the OO-ALC. Over 250 aircraft are maintained at Hill AFB every year. Additionally, more than 16,800 avionics and structural components are repaired or serviced on an annual basis. The base functions as an overhaul facility for landing gear, wheels and brakes, rocket motors, air munitions and guided missiles, photonics equipments, training devices, avionics, and hydraulics.

Hill Field was established in November of 1940. At this time, it was part of the Army Air Corps. The runways were completed in 1941. The name was changed to Hill AFB in 1947 when the army Air Corps became the United States Air Force. Currently, Hill AFB resides on 6,698 acres of land in northern Utah. The base is Utah's largest employer, having a payroll of over $500 million.

The base itself is bounded in the East by the Wasatch Mountains and by the Great Salt Lake in the west. Hill AFB is located on a high plateau, approximately 4,800 feet above sea level. Summers at the site can be hot, with temperatures reaching above 90 °F. Winters on-site are generally expected to be cold with temperatures falling below 10 °F. As a result of scheduling the Dem/Val test at this location during the May time period, weather conditions did not detrimentally influence the performance of the VCPI test.

3.3.2 Test Platform No. 2.

The Mayport Naval Station or MNS is located near Jacksonville, Florida, just north of Atlantic Beach at the mouth of the St. John's River. Approximately two dozen ships are housed at the station, including the USS John F. Kennedy aircraft carrier. The harbor can house up to 34 units, including 2 aircraft carriers. The majority of vessels in the harbor include guided missile cruisers, destroyers, and guided missile frigates.

Approximately 14,000 active duty personnel and 1,400 civilians are employed to support the Mayport Naval Station. The Station encompasses over 3,400 acres and is the third largest naval maintenance facility in the country. The facility was commissioned in December of 1942, and currently supports Navy air efforts for the Naval Air Systems Command (NAVAIR) as well as sea efforts for the Naval Sea Systems Command (NAVSEA).

Pier side elevations range between 5 and 12 feet above water level depending on the tide. For all intensive purposes, the Mayport Naval Station is at or slightly above sea level. Located in Florida, summers are known to be hot and muggy with the temperatures rising above 100 °F. Winters can be pleasant, but temperatures have been known to dip below 30 °F at times. Aside from high heat and humidity, which are typical for Florida during June and July, there were no major weather related issues that influenced the Dem/Val test conducted at this location.

3.4 Current Surface Cleaning Operations

3.4.1 A-10 Corrosion Prevention & Control Facility at Hill AFB, UT

A review of the current pre-paint cleaning operations currently being used on A-10 aircraft in Building 270 at Hill AFB was completed during a single baselining visit. This visit was completed during mid-February 2006, and was used to (1) conduct a depot-level baselining of the A-10 cleaning operation, and (2) conduct a pre-demonstration of the technology on large airframe panels. On-site discussions with HAFB representatives confirmed that the current A-10 pre-paint cleaning operation uses a 3-step PreKote™ process that is approved in T.O. 1-1-8. The various stages in this process are detailed in the Dem/Val Plan that was prepared and submitted in support of this study. The subject visit was also used to document and brief the A-10 engineers and production supervisors on the technical scope and intentions of the VCPI Dem/Val activities. Additional activities included the collection of representative contaminant specimens from the underside wing surfaces of various areas on A-10 aircraft, as a means of documenting as much information as possible on the PreKote pretreatment process that is currently being used to chemically treat the surfaces of A-10 aircraft prior to painting.

As was discussed with the primary stakeholders and A-10 representatives, the VCPI technology was to be used to conduct a real-time assessment of the cleaning efficiency and effectiveness of two different methods of processing an A-10 aircraft with the PreKote pretreatment process. Specifically, for this demonstration platform the VCPI method was to measure the quality of cleaning obtained on heavily soiled aircraft structures using (1) a single grade of 180-grit scrub pads attached to sanding poles (manual operation) and (2) pneumatic sanders (automated operation).

3.4.2 Pierside at Mayport Naval Station, FL

As with the Air Force Dem/Val site, the baselining visit to MNS was intended to provide information related to the actual cleaning and painting operations that are routinely performed by Naval personnel at dockside or pierside. In addition, this visit allowed Battelle representatives an opportunity to brief the Navy representatives on the intentions and scope of the study, as well as to identify any issues that needed to be resolved prior to conducting the Dem/Val test.

Conversations with the NAVSEA Program Manager during the Project Kick-Off meeting and during the preliminary site visit confirmed that a water rinse of painted surfaces is the primary 'cleaning' method used on the hulls of many Navy ships prior to repainting. Specifically, little or no pre-paint cleaning operations are performed during dockside maintenance operations. *Information related to the frequency and efficiency of any current pier-side cleaning operations was incomplete because this data is not tracked by the Navy, ship preservation personnel, or any of the on-site maintenance personnel at the MNS*. In general, the maintenance representatives confirmed that salt and oil/grease residues have a detrimental effect on coating adhesion and corrosion resistance. However, the pier-side environment makes a quality cleaning operation or effective surface water rinse extremely difficult. This limitation forces the NAVSEA maintenance personnel to just cover up the contaminants with a "fresh" layer of paint, and then re-paint on an "as-required" basis to minimize localized rust formation that is typical for ship hulls.

3.5 Pre-Demonstration Testing and Analysis

Prior to arriving at each of the Dem/Val sites, work was completed in the laboratory to confirm the following:

- Current formulations of the respective VCPI dye solutions are capable of adequately labeling grease and oil contamination on the airframe surfaces of an A-10 aircraft at HAFB, and sea salt contamination on the hulls of a ship at the MNS
- Effluent from the respective process operations will not adversely affect the environments into which they (i.e., VCPI dye solutions) are released
- VCPI is completely removed from the substrate immediately after the contamination is labeled and removed by the current DoD cleaning operations
- A suitable self-contained rinse water delivery device or method for each location is feasible and operational at both locations

A summary of the experimental approach and results obtained from the laboratory testing completed in support of the Dem/Val tests is provided in Appendices B and C. Ensuring that each of the above referenced steps or concerns were adequately addressed prevented potential delays or problems with the subject process demonstrations.

In addition to the above mentioned laboratory testing, it was necessary to conduct a pre-demonstration test at the Hill AFB Dem/Val site. This test, which was requested by the A-10 systems directorate, was conducted on large 2024-T3 aluminum alloy airframe panels that simulated contaminated aircraft airframe structures. Information collected from this field-level pre-demonstration confirmed the chemistry and delivery methods for the VCPI solution, labeling efficiency as a function of contaminant loading and cleaning processes, and visible detection limits as a function of substrate finish and lighting conditions within the maintenance hanger. This pre-demonstration also allowed production personnel an opportunity to become familiar with the VCPI technology. A summary of the results obtained from this pre-demonstration test is provided in Appendix D of this report.

No pre-demonstration tests were conducted at the Mayport Naval Station.

3.6 Testing and Evaluation Plan

3.6.1 Demonstration Set-Up and Start-Up

Prior to arriving on-site at each location, the respective VCPI dye solutions were formulated in the proper concentrations for each Dem/Val test location. These solutions were prepared and properly packaged at the Battelle laboratory facility prior to being shipped to the appropriate test location. Additionally, all supplies and VCPI application equipment that could not be transported by Battelle staff traveling to support the project were properly packaged and shipped to each Dem/Val location (i.e., Hill AFB and MNS).

Once equipment and VCPI team personnel were on-site, a final briefing was conducted with the primary stakeholders and production-level supervisors. These discussions helped identify and define the ability of the VCPI dye solutions to function as desired (i.e., application, labeling, detection, and removal), obtain end-user “buy-in”, and to gain permission for VCPI to be released into the surrounding environment. Information related to how the VCPI dye solution(s) would be applied, how long they will be allowed to dwell on the surfaces of the test platform, the cleaning operation, and removal method was fully discussed with the respective DoD representatives. This information was fully detailed in the Experimental Test Plan that was submitted in support of this study.

Baselining activities conducted at both Dem/Val locations served to define the exact locations for the full process tests at HAFB and MNS. Initial conversations with the respective Program Managers and weapon systems engineers confirmed that the A-10 demonstration would be conducted in the Corrosion Prevention and Control Facility located in Building 270 at HAFB, and the Navy Dem/Val test would be conducted on a center section of the hull of a ship that is docked pierside at the Mayport Naval Station in Jacksonville, FL. All equipment required to apply the VCPI dye solutions was adapted to accommodate both platforms.

All efforts were made to contact the respective production scheduling personnel at HAFB and the MNS to validate platform availability. The specific A-10 aircraft (T/N 78-0624) and Naval vessel (USS Halyburton) were not chosen until the team was on-site in order to best interact with each site’s primary mission, and also ensure that the respective test platforms were adequately contaminated prior to testing. This approach minimized the disruption a demonstration would cause on day-to-day activities at each location.

3.6.2 Period of Operation

Full process demonstrations at HAFB and MNS lasted approximately 3 months; however, the official Dem/Val tests at each location only required 3 days. Activities included in the full process demonstration schedule included; process debrief to stakeholders and full-scale Dem/Val participants, equipment construction & set-up, pre-demonstration testing (if required), full-scale Dem/Val testing on test platform structures, clean up, and equipment tear-down time.

3.6.3 Amount/Treatment Rate of Material to be Evaluated with VCPI

Several large sections of the outside hull of a Navy ship and a large portion of an A-10 were used to demonstrate the contamination labeling properties of VCPI dye solutions, and the improved cleaning/painting operations post-VCPI application. A surplus of VCPI test solution was supplied to account for any unforeseen difficulties at each location; however, no more than 5 gallons of VCPI test solution was required for each Dem/Val test platform. The approximate surface area treated on the center hull section of the USS Halyburton was 200 ft^2. Similarly, the surface area treated along the lower Right- and Left-hand wing sections and center fuselage of the A-10 aircraft was approximately 225 ft^2.

3.6.4 Operating and Performance Parameters for the Technology Demonstration

Each of the Dem/Val tests required a similar spray application and removal of the VCPI from the surfaces of the respective test platforms. However, the amount of material used for each test did vary significantly as a result of concerns about post-rinse river contamination at the MNS location. Specifically, the on-site environmental contact at MNS (i.e., Robert Tierney) insisted that no VCPI test solution or associated rinse water be released into the river – before, during or after the demonstration. As a result, Battelle researchers constructed a portable retention system that collected all VCPI and water rinse solutions. In addition, the total amount of VCPI test solution applied to the surfaces of the ship hull was held to less than 1 gallon.

For both test locations, approximately ½-gallon of the appropriate VCPI solution was thoroughly agitated and then transferred to a 1-gallon metal container or reservoir. For the Dem/Val at Hill AFB, the VCPI solution was applied using their HVLP spray guns that were pressurized to ~30 psi. A portable airless sprayer was used to apply the VCPI test solution to the hull surfaces of the USS Halyburton. In both cases, the nozzles on the spray guns/wands were adjusted to provide a fine mist of the VCPI solution to the test surfaces. Production personnel at both Dem/Val locations adjusted the spray to provide a fine mist at a maximum nozzle-to-substrate distance of 2 to 3 feet. Because of the stand-off distance between the dock or pier and hull of the Halyburton, it was necessary to use a 15-foot stainless steel wand or extension to apply the VCPI solution to the test surfaces. A spray pattern similar to the pattern used during an application of the VCPI to the surfaces of the A-10 was obtained by Battelle and the on-site production personnel.

Each of the Dem/Val assessments was able to effectively demonstrate the following VCPI performance criteria:

1. An optimized VCPI formula for the two test solutions, which resulted in (1) an acceptable application rate and residence time on the test surfaces, and (2) a visible detection of contaminant labeling for both solutions
2. Straightforward clean-up and disposal of VCPI test solutions and rinse waters

3.6.5 Experimental Design

The actual demonstrations included the use of two different VCPI test solutions to indicate the cleaning performance prior to painting operations on both the hull of the USS Halyburton and the underside surfaces of an A-10 aircraft. Specific details related to the composition and concentrations of the dyes contained in the respective admixed VCPI test solutions are included in the Laboratory Test Results and Field Demonstration Test Plan provided in Appendix A. For documentation purposes, Table 4 lists the personnel that participated in the Dem/Val tests, as well as their roles and responsibilities.

3.6.6 Product Testing

Prior to on-site demonstration, the final chemical compositions specific to each weapon system platform were tested and validated in the laboratory at Battelle. No written environmental approvals to proceed were required from the test locations prior to scheduling and conducting the full process Dem/Val tests.
All product testing was performed in accordance with the Experimental Plan and Demonstration & Validation Test Plan that were drafted in support of this study.

The non-toxic, non-hazardous nature of the VCPI test solutions eliminated any worker exposure concerns or need for personal protective equipment.

3.6.7 Ergonomics Assessments

This study confirmed that there were no ergonomic issues associated with the use of the VCPI technology, as applied to military aircraft and ships.

3.6.8 Demobilization

All unused VCPI and VCPI dye solutions, spray equipment, and other demonstration supplies were shipped back to Battelle in Columbus Ohio. As appropriate, any VCPI contaminated water rinse solutions collected throughout the demonstration at MNS was transferred to a 5-gallon container and left with the environmental representative for treatment and disposal.

Table 4. Job Descriptions and Responsibilities

Job Title	Assignee	Responsibilities
Project Manager VCPI Demonstration Coordinator	John Stropki (Battelle) Kevin Rose (Battelle)	Coordinate all demonstration activities. Fill out qualitative datasheet and assist in taking various samples and measurements. Lead kick-off and wrap up meetings each day.
Hill AFB Sponsor(s)	Richard Buchi, Glen Baker	Lead and assign personnel's efforts for HAFB; assume responsibility for safety of aircraft or assign designee to assume safety lead; coordinate efforts on location
Mayport Naval Station Sponsor(s)	Scott Sirchio, Robert Tierney	Lead and assign personnel's efforts for MNS; assume responsibility for safety of ship or assign designee to assume safety lead; coordinate efforts on location
Research Support Staff	Bruce Monzyk (Battelle) Nick Conkle (Battelle) Kevin Rose (Battelle) Robert Russell (Battelle)	Observe and document all days; take digital photographs; fill out datasheets. Attend kick-off and wrap up meetings each day. Write reports and documentation.
Other Observers	Production personnel	Observe demonstration and provide input.

3.7 Selection of Analytical/Testing Methods

Table 5 lists equipment requirements, purposes, operators, and suppliers for the VCPI demonstration/validation tests that were conducted at Hill AFB and MNS. As was mentioned in the previous text, a more detailed experimental plan for the respective field-level Dem/Val tests conducted at both locations is included in the Field Demonstration Plan for this study (ref. Appendix A).

Table 5. VCPI Dem/Val Equipment Requirements

Equipment	Purpose	Supplied by	Operated by
VCPI spray applicator	Applying VCPI	Battelle (MNS) and Hill AFB	Battelle (MNS) and Hill AFB
Water supply	VCPI rinse water	Hill AFB or Mayport Naval Station	HAFB or MNS
VCPI specifically formulated for each Dem/Val location	Contamination marker	VCPI provided free of charge to each location by Battelle	Battelle
Clipboards, pens, datasheets, other miscellaneous supplies	Document demonstration	Battelle (small items, such as tape, pens, may be supplied as needed by each facility)	All observers
Record book	Data documentation	Battelle	All observers
A-frame	Pre-screening demonstrations	Hill AFB	HAFB and site observers
Test panels	Pre-screening	Hill AFB	HAFB and site observers

The following text summarizes the methods that were required to prepare and assess the performance of the VCPI dyes and VCPI dye solutions in both the laboratory and field environments. As drafted, the summary has been divided into two sections, which separately address the VCPI dye solution that was evaluated in the A-10 Dem/Val test, and the VCPI dye solution used for the Dem/Val test conducted on the USS Halyburton. The objectives of each demonstration included a spray application of the respective test solutions, visual labeling, and complete removal of dye and contaminant. The VCPI cleaning verification tool was to be used to validate the effectiveness of the chemical cleaners and processing methods used by the maintenance personnel.

Air Force Platform

Specific details related to the formulation, application, and detection of the VCPI dye solution on the surfaces of panels that are similar to the A-10 aircraft are provided in Table 6 and the following text.

VCPI formulation. The formulation that was used for the Dem/Val test conducted at Hill AFB was based on information contained in the SERDP P-1117 Report (ref. Background Section). Specifically, the A-10 wing cleaning test used a VCPI dye formulation that was based on labeling oil and grease (O&G) contamination with Oil Red O [ORO, (CAS No. 1320-06-5)]. For this formulation, a 12,000 ppm or 1.2 % solution of ORO was prepared in the laboratory by dissolving 12 grams of ORO into 120 milliliters of isopropanol (i-PrOH). This dye solution was then added to a 1 liter or 0.5% Xanthan gum solution. The Xanthan gum solution was also prepared in the laboratory by slowing adding 5 grams of Kelzan to 1 liter of deionized water (DI-H_2O). The final dye solution was then heated to a temperature between 35 and 45 degrees C and mixed for approximately 10 minutes.

Table 6. Matrix for VCPI Parameters Used during Air Force A-10 Dem/Val Tests

Parameter Number	Key Parameters and VCPI Tests	Description and Initial Parameter Test Estimates for Laboratory Selection Task ****
1	Applicator sprayer settings	Spray nozzles adjusted to a broad spray, using vendor procedures, to deliver a controlled film (100% wet surface) without excess misting to surrounding structures. Settings recorded during laboratory testing and held fixed for the field-level demonstrations.
2 **	Concentration of ORO, [ORO], in XG*	Determined in laboratory in support of field demonstration test: • Case I: Evaluated XG nearly saturated in ORO @20-25°C ***. • Case II: Reduced [ORO] to lower level if formulation for Case I is found to be excessive for the need. • Case III: Increased [ORO] to increase label color intensity relative to Case I if needed.
3	Spray Amount	Mist spray until 100% of the surface was wetted, then moved to next area to label (rubbing or scrubbing is optional). Field demonstration including fixing the spray amount at “spray until surface is wet”.
4	Scrub time	Two scrub situations were investigated in support of field demonstrations: • Minimum scrub time to remove excess VCPI label to show residual contamination area for cleaning effort. • Complete removal of O&G contamination using scrub time required by T.O. and/or vendor technical literature. Normally at least 3 min, and then more time on spots where additional cleaning is required, as indicated by VCPI.
5 **	VCPI Dwell Time (t_{dwell}, ≥min)	Determined in laboratory testing to be at least 1 minute and no more than 3.
6	Cleanability of painted surfaces	Determine if ORO labeled painted panels representing A-10 surface is cleaned of dye color using Re-Gel cleaner (MIL-PRF-87937B, Type III) or PreKote.

* XG = xanthan gum gelling reagent, used at concentrations < 1%

** Key quantitative parameters were measured in support of lab and field testing. Other parameters were estimated and then fixed at the determined value/settings for the remainder of the testing, and considered for the field testing too.

*** NOTE: Saturated @ ~ -5°C (lower) reagent might be best for full commercialization to meet all storage requirements (out of scope for this project). CAS No. for ORO is 1320-06-5 and for backup, D&C Violet 2, the CAS No. is 81-48-1.

******** Laboratory screening included unpainted and painted Al 2024 T3 panels and test fixtures with defects (rivets and joints/seams) as required.

Technically, the dispersed dye provided a substantive system for labeling surface contaminants. Hence, even though ORO was dissolved in the i-PrOH, it formed a fairly stable fine dispersion when blended with the water-based xanthan gum solution. This dispersion then preferentially released ORO to O&G contaminants once the dispersion was applied to a contaminated surface, and not otherwise, and hence selectively labels the organic contamination. Importantly, after labeling, the gel dissolved and was readily rinsed away simply by applying a water rinse. The finishing water used at Hill AFB was deionized, which was preferred because deionized water does not leave mineral deposits upon evaporation.

VCPI Application. For the subject test platform, the VCPI dye solution was spray applied using a DeVilbiss EXL-520S HVLP suction feed spray gun, with a gun inlet pressure of 30 psi. Once the pressure settings were adjusted on the spray gun to deliver a fine mist of the test solution, no additional changes were required by the end-user. In accordance with the pre-paint cleaning procedures used on the A-10 aircraft structures, all test surfaces were pre-rinsed with low pressure (i.e., 100 psi) water to simulate the surface rinsing that they would see in Building 270 at HAFB, UT. As expected, this rinsing operation did not remove or dilute the concentration of the representative hydrophobic contaminants on the underwing and fuselage surfaces of the aircraft (~225 ft^2). As shown in Figure 6, the surfaces of the aircraft structures were sprayed until uniformly wetted with the VCPI dye solution, allowed to dwell (~ 1 minute) on the surfaces of the structures being investigated, and then rinsed by a fire hose with deionized water.

Figure 6. Application and Removal of VCPI Test Solution to Lower Fuselage of A-10 Aircraft at Hill AFB, UT.

VCPI Detection and Removal. During all laboratory assessments, the individual Al2024-T3 test panels were weighed to the nearest 0.0001 grams on an analytical balance to record the weights of cleaned and VCPI labeled panels. Additionally, the labeled surfaces of panels were visually inspected using a Light Box that simulates Daylight, Incandescent and Cool White Fluorescent lighting. A portable spectrophotometer or CIE colorimeter was used to measure the L*a*b* color coordinates of labeled and cleaned panels to validate that the VCPI dye solution effectively labeled the hydrophobic contaminants, and the cleaning operation thoroughly removed the labeled contaminants.

For the pre-demonstration trials and full-process field demonstration, Battelle engineers were only able to use two analytical methods to measure the degree and density of VCPI dye labeling of hydrophobic contaminants on the A-frame test panels and underside wing and fuselage surfaces of the A-10 test aircraft. These methods included; visual (qualitative) and water break (qualitative). A third more quantitative method (i.e., CIE colorimetric) could not be used because of the short period of time allotted for the actual demonstration, and the requirement to maintain a continuously wetted surface. Specifically, for the demonstration the A-10 production crew was anxious to conduct the demonstration and then finalize all cleaning of the aircraft to ensure that the painters on the afternoon or night shift could complete masking operations. There was no time in the demonstration for the CIE colorimetric inspections. Any significant measurement errors were reduced by using similar inspection methods, personnel, and equipment.

All VCPI labeled contaminants within the test sections of the aircraft were successfully removed during subsequent aircraft structural cleaning operations. These operations include the 2nd and 3rd stages of the 3-step PreKote pretreatment process that was approved in T.O. 1-1-8. This subject pre-paint surface preparation process includes a spray application of PreKote, which is then followed by a manual Scotchbrite™ scrubbing operation and deionized water rinse. As was defined in the Experimental Test Plan, HAFB representatives elected to assess the VCPI technology early during the aircraft cleaning operation as a quality control check on cleaning efficiency. As designed, the multi-step PreKote pretreatment process successfully removed any labeled surface contaminants that remained on the surfaces being investigated during the Dem/Val test. Visual and water break inspections even confirmed that there were detectable differences between the cleaning efficiency of the two T.O. 1-1-8 approved scrubbing techniques. If completed in a thorough manner, the power scrub method thoroughly cleans the surfaces and removed both contamination and the VCPI label. The stakeholder and production supervisors both agreed that the VCPI technology could be a good quality control tool for measuring how good the various production crews operating on different shifts are at implementing the PreKote surface treatment operation.

Post-demonstration visual inspections confirmed that there were numerous small areas on unmasked and painted landing gear components that were labeled with the red colored VCPI dye. As shown by the arrows in Figure 7, these typical areas visually "stood out" because the topcoat color on the landing gear components was high-gloss white.

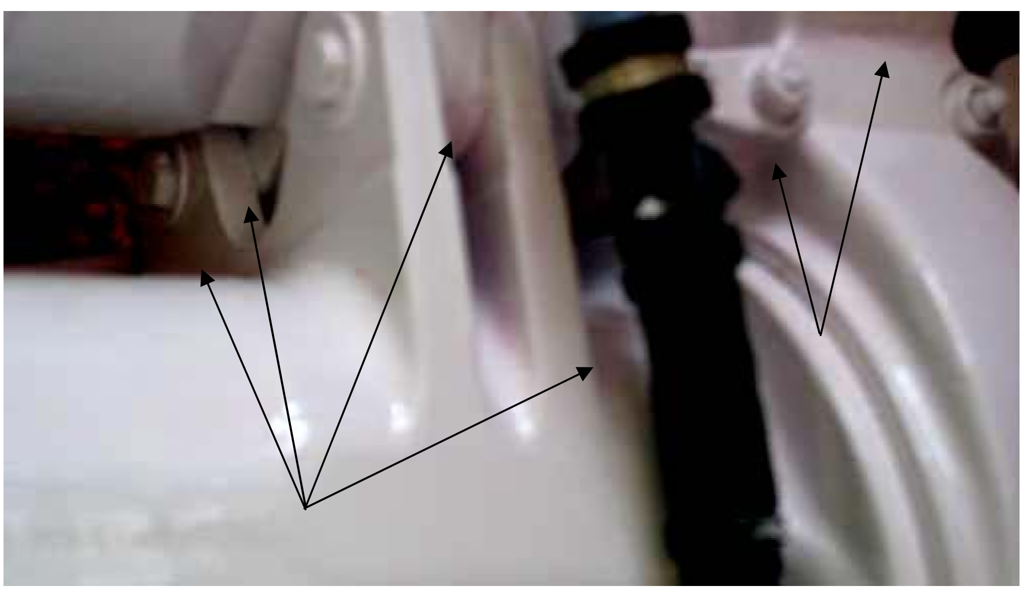

Figure 7. VCPI Staining of Forward Landing Gear Components.

Numerous areas on the parts were stained. In addition to the localized staining of these component parts, there was a significant staining of the hanger floor (see Figure 8) immediately below and adjacent to the aircraft. Production personnel also complained about the heavy staining of their coveralls and boots. The staining issue represented a major drawback for the technology demonstration, especially with the difficulty in removing the stains from the white colored topcoat on the landing gear components. The A-10 management team and production supervisor overseeing the demonstration did not want to incur the cost and downtime associated with stripping, cleaning, masking, and repainting the stained gear components. Fortunately, a COTS chemical solvent was identified and used on clean white cotton clothes to safely remove the red stains. No loss of coating gloss or damage to the white topcoat was evident throughout the cleaning operation.

Figure 8. Post-demonstration VCPI Staining of Maintenance Hanger Floor

<u>Navy Platform</u>

Specific details related to the formulation, application, and detection of the VCPI dye solution on the surfaces of coated HY-80 steel alloy panels similar to the Navy ship hull are provided in Table 7. Information and results collected throughout the process demonstration conducted on a section of coated hull from the USS Halyburton is also discussed in this section of the report.

Table 7. Matrix for VCPI Parameters Used for Navy Ship Hull Dem/Val Test

Parameter Number	Key Parameters and VCPI Tests	Description and Initial Parameter Test Estimates for Laboratory Selection Task ***
1	VCPI applicator sprayer settings	Spray nozzle was adjusted using vendor procedures to deliver a controlled film (100% wet surface) without misting to surrounding surfaces. All settings were obtained during laboratory test and fixed for the field testing.
2 **	Concentration of Food Coloring Formulation Ingredients*	Determined during laboratory testing phase of study: • Evaluated food coloring formulation @20-25°C at SERDP 1117 test concentration and test conditions, with and without xanthan gum, the latter in the ~ 0.01-0.1% range. • Final Dem/Val formulation is ≥ 99.8% water.
3	Spray Amount	Spray until 100% of the surface was , then move to next area to label (rubbing or scrubbing is optional). Dem/Val plan includes fixing the spray amount at “spray until surface is wet”.
4	Rinse Time (t_{rinse} , sec)	• Minimum scrub time to remove excess VCPI label to show residual contamination area for cleaning effort. Laboratory testing confirms that water rinse adequate and no scrubbing required. • Sea water residue or contamination is removed using rinse-only time required by practice accepted by the Navy.
5 **	VCPI Dwell Time (t_{dwell}, ≥min)	Laboratory tests confirm optimum dwell time of 1 minute.
6	Cleanability of painted surfaces	VCPI dye is removed from painted panels representing hull surface using only low pressure rinse water or compliant cleaner. No staining was visually evident.

* Food coloring candidates are Food Blue 2/Food Green 3 and the CAS No's are 3844-45-9 and 2353-45-9 respectively.
** Key quantitative parameter measured in lab testing. Other parameters were estimated and then fixed at the determined value/settings for the remainder of the laboratory and field testing.
******* Laboratory screening used only enameled HY 80 steel panels and test fixtures with bias (bolt heads and joints/seams) as required.

VCPI formulation. From an environmental perspective, the VCPI formulation used for the demonstration conducted on the Navy ship hull test platform required that all chemicals and dyes must be non-harmful to the environment and must <u>not</u> adversely change the visual color of the brackish river water immediately surrounding the hull surfaces being processed. In addition, the environmental management representative at MNS stated that the VCPI dye solution must be non-toxic to aquatic life and to the end-users or process operators.

The VCPI dye selected for this test platform was determined to be Food Green 3 (FG3) or Fast Green FCF, CAS No. 2353-45-9 for it's ability to selectively label soluble salts on coated HY-80 steel panels, without staining the painted surfaces. A 500 ppm or 0.05 % concentration of FCF was added to a solution comprised of 0.3 - 0.5% xanthan gum gelling agent [provided by C.P. Kelco (a Huber Company) as product Kelzan, industrial grade xanthan gum] dissolved in deionized water. The xanthan gum solution served both as a diluent and a coupling agent or carrier for the FG3/FCF dye.

The dye concentration used for the Navy VCPI dye solution was selected from the SERDP report of March 15th, 2002, section 7.2.1.22, pg. 30 and Figure 7.2.1.6, which stated "That soluble salts (as seawater) can be rendered visually apparent by using FG3/FCF". The green color of this particular dye (solution) was a positive asset for the pierside sea water demonstration.

VCPI Application. The Navy VCPI dye solution was spray misted onto a 10' by 20' section of hull on the designated ship selected to participate in this Dem/Val test. The airless sprayer and its operation were previously defined, and the same XG-water base VCPI formulation used for the AF application was used for the Navy application. However, the VCPI dye or label for the Navy platform consisted of the FG3/FCF dye which was selected to track with dissolved corrosive salts.

In accordance with the re-paint cleaning procedures used on the surfaces of ship hulls, all surfaces within the designated 10' by 20' test section are pre-rinsed with water to simulate the fire hose water rinsing that these surfaces would see during normal hull pierside maintenance operations. Prior to drying, these surfaces of the hull were sprayed until uniformly wetted with the VCPI dye solution, allowed to dwell (~ 1 minute) on the surfaces of the structures being investigated, and then rinsed with tap water. The surfaces of the hull within the test section were then inspected to determine the labeling effectiveness of the VCPI dye solution. Figures 9 and 10 serve to document the application and containment of VCPI solution on hull test sections.

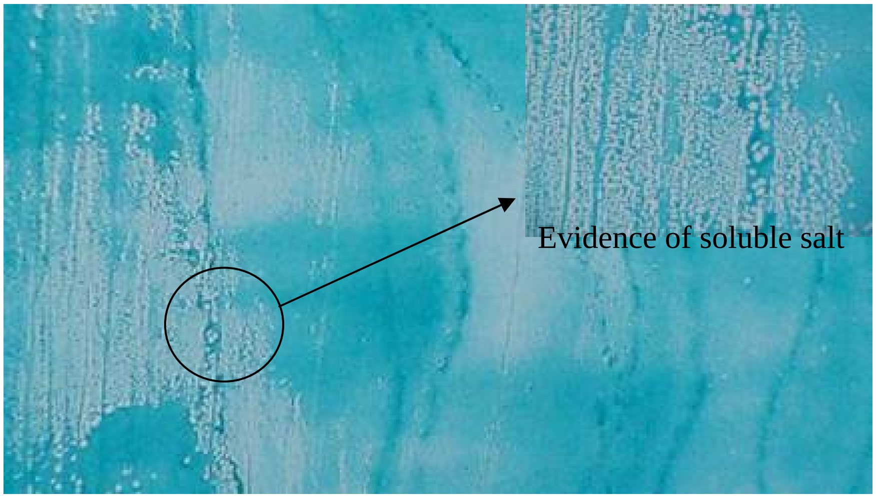

Figure 9. Application of VCPI Test Solution to Section of Hull on USS Halyburton

The effectiveness of labeling soluble salt contaminant with VCPI is shown for a second area within the test section in Figure 11.

VCPI Detection and Removal. The following three methods were used for detecting and verifying the presence and density of VCPI dye on the painted surfaces of laboratory test panels.

- Weight Change - Painted HY-80 steel panels were weighed to the nearest 0.0001 grams in a constant temperature/humidity laboratory. Weight loss/gain data tracked the degree of contamination and labeling throughout the laboratory phase of testing, as well as to identify the effectiveness of the post-cleaning rinse process.
- Light Box Visual Comparison – Test panels were analyzed for visual comparison purposes under the lighting of conditions of Daylight, Incandescent and Cool White Fluorescence. Visual observations under the various lighting conditions were conducted to compare the surfaces of post-labeled panels to non-labeled test blanks. All panel surfaces were inspected only after having been static air dried.
- Data Color (color space coordinates) - See Report SERDP – P1117 for analytical protocols and data reduction methods. In principal, the surfaces of the individual panels were measured individually and the L*a*b* values reported for color variation between the clean un-contaminated panel and the post Contaminated/Labeled/Rinsed values. This data set provides for a more mathematical or quantitative means of comparing the results.

Figure 10. VCPI and Rinse Water Containment Equipment on Hull Surface

Figure 11. Post-rinse VCPI Labeling of Soluble Salts on Hull of USS Halyburton

For the full process field demonstration, Battelle was able to only use two different methods for measuring the degree and density of VCPI dye labeling of soluble salt contaminants on the hull surfaces of USS Halyburton. These methods include visual (qualitative) and water break (qualitative). The CIE colorimetric method could not be used because of the short application, dwell, and removal time available for the VCPI demonstration. As was mentioned for the Air Force Dem/Val test, any measurement error was reduced by using similar inspection methods, personnel, and equipment. As appropriate, the location and density of contaminant labeling across the surfaces of the test section was documented using a digital camera.

4. Performance Assessment

4.1 Performance Criteria

General performance criteria used to evaluate the VCPI technology during the laboratory and field tests are summarized in Table 8. Throughout the Dem/Val test, the project team observed the primary characteristics noted in Table 8 and weighed the results of the respective Dem/Val tests against the performance requirements that were conveyed to the stakeholders during all project briefings. As outlined, these requirements were expected to represent the minimum criteria for acceptance and possible implementation into a DoD production environment.

Table 8. Performance Criteria

Performance Criteria	Description	Primary or Secondary
Factors Affecting Technology Performance	*Application & Labeling Efficiency*	**Primary** Selected VCPI dyes are non-toxic; however, it was necessary to assess modified solution chemistries to improve user acceptance on the basis labeling efficiency, detection and removal.
	Dwell Time	
	Detection Limits (Lighting)	
	Cleanability	
	Staining	
	Environmental	
Product Testing	*Spray test*	**Primary** The spray characteristics of VCPI dye solutions were comparable to the dispersion characteristics of liquid cleaners.
	Compatibility with full-scale DoD production cleaning equipment	

Performance Criteria	Description	Primary or Secondary
Product Testing	*Certification Testing*	**Secondary** If the demonstrations are successful, process QA testing and certifications will be completed and incorporated into applicable Process Orders or Technical Orders. No special permission to proceed with Dem/Val was anticipated.

4.2 Performance Confirmation Methods

Production-level supervisors and processing personnel at the respective Dem/Val test locations, as well as the primary stakeholders and Battelle engineers observed each VCPI process demonstration. Pre-demonstration discussions were conducted to confirm that all performance and processing related requirements were identified, and that the subject VCPI dye test solution(s) are commensurate with the existing cleaning processes and equipment. It was suggested during these discussions that a production-level usage of the VCPI technology would require more effort than currently being expended with the T.O. 1-1-8 approved water break test; however, this additional effort should be offset by an improved cleaning efficiency and reduced coating system failures. All Dem/Val testing efforts were to concentrate on minimizing the time and level of processing associated with implementing VCPI into the current Air Force or Navy pre-paint cleaning operations.

An overview of the results of testing conducted at both Dem/Val locations is presented in Table 9. Collectively, these results were used to determine if the VCPI cleaning Dem/Val tests were successful in meeting the stakeholder expectations. Post-test discussions with individuals participating in the respective demonstration tests were also used to determine if this technology fits into current maintenance activities. The results and discussions confirmed that the intended application for VCPI at both sites did not represent an improvement to existing processes.

Table 9. Expected Performance Confirmation Methods

Performance Criteria	Expected Performance Metric	Performance Confirmation Method	Actual Performance
Improved Cleaning Operations			
Manpower	Cost of operation	Process efficiency (i.e., less personnel, reduced cleaning time)	*No improvement in process efficiency noted w/ VCPI*
Consumables	Cost of operation	Consumable usage (i.e., reduced cleaner and water usage)	*No Reduction in consumables noted w/ VCPI*
Improved Coating Performance			

Performance Criteria	Expected Performance Metric	Performance Confirmation Method	Actual Performance
Field- and Depot- Repairs	Reduced maintenance	Less coating failures	*Unable to measure within duration of study*

4.3 Data Analysis, Interpretation and Evaluation

All data and information collected during the Dem/Val tests at the participating DoD maintenance facilities confirmed that there were several factors that limited a complete success of the Dem/Val tests conducted on the VCPI technology. Several of the more important factors included an extra processing step was required to apply the VCPI dye solution, the solution dwell times and surface inspection times that lengthened the time required to clean structures, an additional clean-up of mislabeled structures or surfaces (i.e., overspray), and discharge restrictions associated with the Navy ship hull demonstration. These operating conditions did go “above and beyond” the requirements of a normal cleaning operation that relied on a simple real-time water break test for cleaning verification. It should be noted; however, that both demonstrations confirmed that the VCPI dye solutions were capable of labeling surface contaminants. The result represents a positive result in terms of the subject ESTCP study. The Air Force demonstration also confirmed that the VCPI cleaning verification technology was capable of discerning differences between the manual and power scrubbing techniques, which was one of the goals of the study. This result supported statements made by the production supervisors and stakeholders that suggest that VCPI would be a “great” Quality Control tool. Specifically, it was suggested that VCPI could be used to determine the cleaning efficiency of experienced and inexperienced production personnel that are tasked with removing surface contamination from structures prior to completing repainting operations.

A consensus obtained from the stakeholders after conducting the Dem/Val tests indicated that the VCPI was capable of quickly labeling the specified surface contaminants, which was the primary objective of the study. The solution chemistries were carefully selected to minimize the possibility of dye related staining of adjacent structures; however, the overall success of the test conducted on the A-10 aircraft was influenced by a lack of protection or masking of painted landing gear components. Normal pre-paint processing of the aircraft with approved cleaning solutions do not have a visible effect on these structures, which confirms a need to better protect the structures if the VCPI technology is used a production-level cleaning verification tool.

A visual detection of dyed soluble salt residues on the hull of the Navy ship also represented a successful demonstration tests for the VCPI technology. However, based on discussions with the Navy stakeholder and on-site environmental manager it’s very unlikely that VCPI would be used as a pierside cleaning verification tool. This statement is solely supported by the fact that all test and rinse solutions must be collected from the surfaces being cleaned. The dye solution selected for this demonstration is not environmentally toxic or hazardous; however, the perception of damage is enhanced by any colored plumes released into the water surrounding the ship.

Demonstration testing did confirm that a release of the dark green colored VCPI solution into the brackish water resulted in a local plume that quickly dissipated.

5. Cost Assessment

5.1 Cost Reporting

Because of the "low-tech" nature of normal large area cleaning operations, cost savings and technology payback issues were considered to be very critical in the production-level evaluation of the VCPI technology. Based on available laboratory data and data collected from the full process demonstrations, Battelle attempted to estimate all capital and operating costs associated with the VCPI technology. All efforts were made to identify, qualify, and assign environmental costs to the baseline and VCPI processes. One factor that significantly influenced the accuracy or validity of the baseline data is the information that was available from maintenance directorates at MNS and Hill AFB. Specifically, all stakeholders and maintenance representatives stated during the initial project briefings and pre-demonstration trials that accurate and detailed cost information on the respective cleaning operations would be limited because of the simplicity of the routine cleaning operations and a limited tracking of manpower and materials costs. It should be noted that the quantity and quality of data collected from Hill AFB representatives was considerable more than the data collected from MNS. The pre-paint cleaning of Navy ship hulls includes a water rinse, with little or no cleaning agents and agitation. This condition is considered the main reason why the coatings applied to the coated hull surfaces have poor adhesion and service life.

5.2 Cost Analysis

The cost analysis completed in support of this study considered all available capital, operating, and environmental costs associated with the baseline or current cleaning operations and the experimental or VCPI cleaning process being demonstrated during the respective Dem/Val tests. A summary of the information available to support the cost analysis generated during this study for the subject technology is provided in the following text.

5.2.1 Cost Drivers

For the analysis of this technology several independent cost drivers were used. These cost drivers included capital cost, annual equipment maintenance, material usage, utility costs, hazardous waste disposal, and any recurring environmental compliance costs.

5.2.2 Cost Basis

For the project's cost assessment, the data confirms that the VCPI technology did not reduce the manpower and consumables or improve the overall quality and efficiency of depot-level cleaning operations conducted on large area surfaces of military equipment. However, there are other non-aircraft and ship related applications for which the technology may be applicable and advantageous. The use of the VCPI technology was to be considered for these other applications after the stakeholders and personnel participating in the Dem/Val tests validated the economic and production benefits; however, this validation did not occur as a result of the demonstrations.

Available cost data used in support of this economic analysis was collected throughout the Dem/Val tests. Additionally, a series of detailed discussions were conducted with the stakeholders, production supervisors, and maintenance personnel participating in the respective demonstrations. As discussed in Section 3.4 of this report, the current chemical cleaning operation completed on the external structural components of Air Force aircraft and Navy ships includes a removal of surface contamination that may compromise primer or coating adhesion. Figure 12 shows how the VCPI technology can supplement the current cleaning operations.

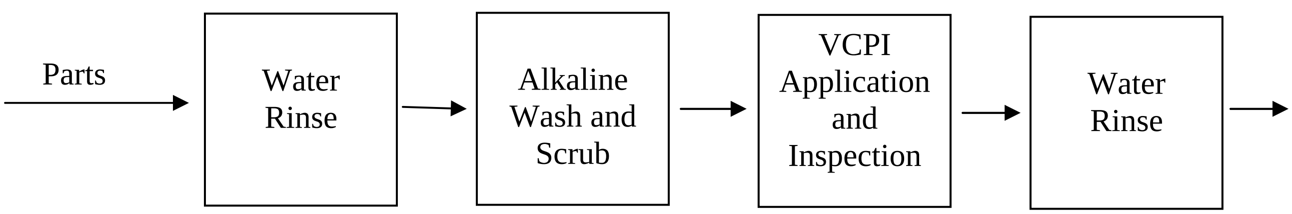

Figure 12. Simplified Chemical Cleaning Operation for Aircraft and Ship Structures

The maintenance cost data for the two demonstration platforms was most comprehensive for the A-10 demonstration. This data was readily available because of the frequency of the PreKote cleaning operations completed on this weapon system. In addition to this aircraft, the PreKote surface pretreatment operation is used exclusively of F-16, T-36/37, and C-130 aircraft maintained at Hill AFB. This process is considered an environmental replacement for the T.O. 1-1-8 approved chromate conversion coating.

Based on the feedback received from the personnel surveyed at the Air Force depot facility, the approximate A-10 aircraft throughput and approximate baseline annual operating usage quantities for this cost analysis are provided in Table 10.

Table 10. Annual Usage for the Baseline Chemical Cleaning Operations Completed on A-10 Aircraft Maintained at Hill AFB, UT*

Annual Number of Aircraft Cleaned	48 aircraft/year (average)
Annual Material Usage • Alkaline Cleaner (B&B ReGel) • PreKote® pretreatment • Solvent (Isopropyl alcohol or IPA) • Safety Glasses • Gloves • TyVek Suits	 720 gallons/year 960 gallons/year 368 gallons/year 70 pairs/year 300 pairs/year 250 suits/year
Annual Utility Usage • Deionized Rinse Water	 576,400 gallons/year
Annual Waste Management • Hazardous Waste Disposal	 <300 pounds/year

* - information provided by G. Baker at Hill AFB, UT.

The following data and assumptions were used in evaluating the baseline chemical cleaning operations completed on the A-10 aircraft. As was mentioned in the previous text, there was limited baselining information available for the non-dry dock cleaning and repaint operations conducting on the external hull surfaces of Navy ships. Consequently, most of the baselining data and analysis used to define the economic benefits associated with the VCPI process was obtained for the A-10 aircraft.

- Hill Air Force processes an average of 48 A-10's annually
- The reworking or recleaning of soiled surfaces of structures represents approximately 10 percent of the total chemical pre-paint cleaning operation
- A price of $9.00/gallon was used for alkaline cleaner
- A price of $17.50/gallon was used for pretreatment
- A price of $4.67/gallon was used for solvent cleaner
- A unit cost of $3.00/pair was used for safety glasses
- A cost of $0.13/pair was used for gloves
- A cost of $2.75/suit was used for TyVek suits
- Waste management data and associated cost is based on actual numbers for the 2006 calendar year for disposal of rags, PPE, filters, and solid residues
- Chemical cleaner usage data is based on actual numbers for 2006 fiscal year
- Environmental compliance costs are based on compliance sites that are associated with the baseline chemical cleaning process

The following data and assumptions were used in evaluating the VCPI cleaning process that would supplement the existing operations used on the A-10 aircraft at Hill AFB, UT.

- Annual usage of the alkaline cleaner currently being used would not change because this production step is required before application of the PreKote pretreatment materials and subsequent process
- Assumed 75% reduction in cleaning rework

- Assumed 25% increase in additional rinse water usage and related post-pretreatment clean-up of VCPI residues
- Assumed 25% increase for annual usage of gloves and TyVek suits
- Assumed negligible reduction for annual hazardous waste disposal amounts
- Environmental compliance cost reduction calculated is for the elimination of the chemical cleaners and PreKote pretreatment associated with rework operations. No additional environmental compliance costs are associated with an implementation of the VCPI technology
- Assumed negligible capital equipment cost and associated maintenance costs

5.2.3 Cost Comparison

A comparison of the baseline and VCPI cleaning processes at the Air Force demonstration site was performed in an effort to assess the economic benefits of using the VCPI technology to verify the cleanliness of large area surfaces. The results obtained from this comparison are provided in Table 11.

Table 11. Comparison of Process Costs

	Baseline Scenario Chemical Cleaning	**Alternative Scenario Chemical + VCPI Cleaning**
Initial Investment Cost		
Capital Equipment	$0	$0
Annual Operating Cost		
Direct Materials:		
Alkaline Cleaner	$6,480	$6,480
PreKote Pretreatment	$16,800	$16,800
Solvent	$1,718	$1,718
Safety Glasses	$210	$210
Gloves	$39	$58
Suits/Coveralls	$687	$859
Equipment Maintenance	$2,500 (est.)	$3,125 (est.)
VCPI Solution	$0	$2,880
Utilities: Rinse Water	$8,112	$10,140
Waste Management: Hazardous Waste Disposal	Negligible	Negligible
Environmental Compliance Recurring Cost	N/A	N/A
Total	$36,547	$42,270

The cost summary provided in Table 11 indicates that an implementation of the VCPI technology into the cleaning operations of the A-10 weapon system would result in a slight increase in process-related costs. The majority of this increase would be associated with the preparation and clean-up of any VCPI dye residues. There is a negligible cost associated with the actual VCPI materials, therefore the cost differential would be directly related to the labor costs associated with preparing the VCPI dye solution, applying it to the large area surfaces and then the extra cold water rinsing down of the treated structures and surrounding processing areas within Building 270 at Hill AFB, UT. A slight increase in the amount of rinse water consumed would also be factored into the cost comparison. Negligible reductions in the amount of hazardous wastes would be realized with an implementation of the VCPI technology, as the existing Prekote pretreatment process is environmentally safe, and produces minimal environmental waste products that require treatment or disposal.

It is estimated that similar increases in production-related costs would be observed with the cleaning operations conducted on other Air Force weapon systems; however, the overall process costs don't take into consideration increases in the labor required to process the respective aircraft or the savings attributed to a cleaner structure which contributes to a more durable corrosion prevention and control system. The latter metric was difficult to quantify on this project because of schedule; however, engineering logic suggests that a cleaner airframe surface prior to pretreatment and primer application would result in a more tenacious primer to substrate adhesion bond and superior corrosion resistant system.

Under the conditions of the Hill AFB Dem/Val test, the labor costs associated with processing the Outer Mold Line (OML) surfaces of aircraft structures with the VCPI test solution is estimated to be 25 to 40 percent higher than the costs incurred using the conventional process because of the extra steps required to apply the solution, inspect, and then completely remove it from <u>all</u> contacting surfaces. These costs could possibly be reduced if there was a way to incorporate the VCPI solution into the final rinse water instead of having the application segment of the process be an extra processing step. This option was discussed with the Air Force stakeholders at Hill AFB and the A-10 system engineers; however, for this study the A-10 engineers were interested in using VCPI as a tool for detecting any differences in productivity and cleaning efficiency for the two Prekote scrubbing methods (i.e., pole or power). As a result, the VCPI test solution had to be added as an extra step between the 1st stage scrubbing and water rinse cycle. This processing procedure was also recommended because it allowed the production staff a "real-time" opportunity to completely remove all VCPI dye residues during the 2nd stage scrubbing/rinse cycle, and prior to primer coat application.

Based on the current pierside hull cleaning operations (i.e., alkaline cleaners and cold water rinse) used by the Navy, Battelle is estimating that the implementing of VCPI into the Navy fleet would significantly increase processing costs. These increases would include labor, materials and the indirect environmental burdens associated with the application and removal of the VCPI dye solutions from the hull surfaces. Additional permitting costs would be incurred if the test solution was allowed to be rinsed directly into the surrounding waterways.

5.2.4 Life Cycle Costs

Normally, an ECAM economic analysis would be conducted to summarize the investment criteria required to validate the benefits associated with implementing the VCPI technology into a DoD maintenance facility. This analysis was not conducted because of the lack of major capital and operating costs associated with the technology. As a result, the life cycle cost of the VCPI process was not calculated based on the following considerations: (1) insignificant facility and equipment capital costs, (2) limited process related start-up, operations and maintenance issues/concerns, (3) negligible demobilization costs, (4) no equipment replacement costs, and (5) no major future environmental compliance liability.

6. Implementation Issues

6.1 Environmental Permits

In order to use the VCPI technology ‘in-the-field’, a series of low-level environmental approvals would be required at Air Force and Navy maintenance facilities. The level of approvals would be considered stricter and mandatory if the Navy is interested in using this technology pierside on the external surfaces of Navy ships. Specifically, it was very apparent during the initial phases of the Dem/Val test at MNS that there was to be <u>no</u> release of any foreign liquids or substances into the river basin surrounding the Dem/Val test platform (i.e., USS Halyburton). Consequently, Battelle worked closely with the Navy stakeholder and MNS personnel to build a portable fixture that was able to rest against the hull of the ship and contain a majority of the VCPI dye and associated water rinse materials. Combined with a low level use of the VCPI solution, the Battelle collection system was able to capture or contain a majority (~90 percent) of all chemicals that were applied and rinsed from the hull of the Halyburton. MNS environmental management representatives stated that a discharge permit would be required to release any VCPI into the waterway, even if the dye was environmentally safe and non-toxic to the aquatic life. The state of Florida is very strict on the release of any chemicals into its rivers, lakes, ponds, and streams.

Conversely, there were no environmental issues associated with the use of the VCPI technology on A-10 and other weapon systems at Hill AFB. This condition may be in part due to the fact that the dye and water rinse was non-toxic and there is an on-base Industrial Waste Treatment Plant (IWTP) that is responsible for processing all aircraft processing wastewater prior to release back into the environment. This facility was contacted during the pre-demonstration briefing at Hill AFB and advised of the project and possibility of releasing a non-toxic dye solution into the building drainage system. The environmental office and base-level IWTP engineers responded by saying that there were no environmental permitting issues identified in support of testing, and or using, the VCPI technology at Hill AFB.

It should be acknowledged that the each of the chemical constituents used in each of the two VCPI test solutions evaluated in support of this ESTCP program have no environmental restrictions or limitations on commercial use. *As presented during the SERDP program, all efforts were made by Battelle to formulate the VCPI technology from food-grade dyes that are used in cosmetics and commercial products*. However, there will always be concerns when exposing personnel to the dyes as well as releasing them into the environment. Because of these concerns, a small-scale, fully-contained pre-demo trial may be required at any future maintenance facilities that are interested in demonstrating or supporting the VCPI technology.

6.2 Other Regulatory Issues

No other regulatory issues associated with the VCPI technology were identified throughout the course of the Dem/Val tests completed in support of this study.

6.3 End-User/Original Equipment Manufacturer (OEM) Issues

End users for the subject VCPI technology included the Navy and USAF maintenance, Quality Control (QC) personnel, and Civil Engineering staff. Specific concerns that these representatives and the primary stakeholders had at the completion of the Dem/Val tests included:

1. Effectiveness (ability to visually indicate surface contamination) – VCPI effectively labeled the targeted contaminations
2. Toxicity – the VCPI formulations evaluated during this study were non-toxic
3. Environmentally friendly – the VCPI formulations selected and used in the two demonstrations were non-hazardous to the environment; however, the Navy required a containment
4. Compatibility with current cleaning equipment and operations – the VCPI technology was compatible with current Air Force A-10 specific cleaning equipment and approved operations. However, an implementation into the current "wash-pretreatment" cleaning operations would not be feasible because of the extra time required to protectively mask already painted structures to avoid staining. In addition, more time would be required to apply the test solution to the pre-cleaned surfaces, inspect, and then completely remove any remaining dye-contaminants from the surfaces of the treated structures. The Air Force did comment that the VCPI technology would be a useful tool for measuring the cleaning efficiency of different production crews working the day, afternoon and night shifts.
5. Implementation of the technology for pierside use on Navy weapon system platforms would require a rinse water collection system that eliminates discharge into the water surrounding the ship.
6. Cost – there is an increased cost associated with implementing the VCPI technology into current pre-paint cleaning operations.

The demonstration plan drafted in support of this ESTCP study was designed to generate the needed operational and cost data to meet these concerns. Because these tests were designed for a full-scale test, the testing addressed the scale-up and commercialization issues associated with the subject technology. VCPI Dem/Val testing was also expected to provide an opportunity for aircraft and ship maintenance personnel to observe the VCPI technology in operation and to witness the labor required, as well as an opportunity to assess the ease of operation. Several assumptions may have to be made in order to accurately determine the cost/benefits associated with this technology due to a lack of documented data for ship and aircraft maintenance schedules and required maintenance.

During the program and at its conclusion, Battelle strived to disseminate all available information associated with the VCPI technology, the demonstration plan, and the results of the Dem/Val tests. A review of this information and resulting conclusions suggest that the performance goals of the Dem/Val tests were compromised by additional processing steps required to apply, remove, and clean the dye solutions from the structures being cleaned during the respective demonstrations. In addition, the costs of using the VCPI technology as a cleaning verification tool are slightly higher than the costs associated with baseline cleaning operations. and as a result the Battelle team will not attempt to commercialize the subject technology or finalize a contract with a licensee to open the market for the full-scale DoD and commercial use.

7. References

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7. Colour Index, 3rd Ed., Volumes 1-5, 1971, The Society of Dyers and Colourists, P.O. Box 224, Perkin House, 82 Grattan Road, Bradford, Yorkshire BD1 2JB, England, and American Association of Textile Chemists and Colorists, P.O. Box 12215, Research Triangle Park, NC 27709, USA.

8. “Food Chemistry,” Third Ed., O.R. Fennema, Ed. Mercel Dekker, Inc. (New York, NY) (1996). Chapters 10 (Colorants), 12 (Food Additives), and 13 (Toxic Substances).
9. FED-STD-141 (Section 9).

8. Points of Contact

The points of contact are noted in Table 12.

Table 12. Points of Contact

Contact Name	Organization Name Address	Phone/Fax/Email	Role In Project
John Stropki	Battelle 505 King Ave. Columbus, OH 43201	614-424-5414 Stropki@Battelle.org	Project Manager
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Scott Sirchio	Naval Surface Warfare Center (NAVSEA) Carderock Division Code 6301 9500 MacArthur Boulevard West Bethesda, MD 20817	301-227-5196 Scott.Sirchio@Navy.mil	Navy Coordinator and Principal Investigator
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Appendix A
Laboratory Test Results and Field Demonstration Test Plan

Environmental Security Technology Certification Program
(ESTCP)

Laboratory Test Results and Field Demonstration Test Plan

for

Field Validation of
Visual Cleaning Performance Indicator (VCPI) Technology
at Mayport Naval Station (MNS) and Hill AFB (HAFB)

April 10, 2006

PREFACE

This report was prepared by Battelle under Contract Number FA8601-05-F0011, Subcontract Number 050200222, Subtask 012 for the Environmental Security Technology Certification Program (ESTCP).

We wish to acknowledge the invaluable contributions provided by the following organizations in the creation of this document:

- United Stated Air Force
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- Naval Surface Warfare Center Carderock Division
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Laboratory Test Report and Field Demonstration Test Plan

for

VCPI Mayport Naval Station and Hill AFB

Submitted as a Deliverable

on

Contract No. FA8601-05-F0011
Subcontract No. 050200222
Subtask 012

April 2006

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1.0 Introduction

Surface coatings applied to Department of Defense (DoD) equipment (i.e., aircraft and naval vessels) provide critical roles in controlling losses to corrosion and enhancing ‘stealth’ operations of the United States (U.S) defensive fleet. These coatings perform optimally when applied to clean surfaces that are free from contamination, including oil and grease and soluble salts. If surfaces are not properly prepared during these surface finishing procedures, there may be a premature failure of these chemical pretreatments or conversion coatings as well as the protective organic coatings. Coating failure compromises the corrosion protection properties of the total system, reduces operability, increases maintenance costs and efficiencies, and results in a less-than-superior appearance of the equipment. Failure of these coatings can also lead to release of hazardous materials into the environment.

In some instances, to insure that surfaces are clean, there is a tendency to over clean to reduce the frequency of the failures associated with under cleaning. Over cleaning a substrate consumes production time and capacity, reducing process efficiency and increasing waste stream volume production and waste handling costs thereby increasing the cost to maintain the aircraft or ship. In other instances, surfaces are significantly under cleaned, and processes such as painting occur, but tend to fail at a much greater frequency than necessary. This increases the need to repaint each aircraft or vessel, using costly raw materials, and personnel time that might be better spent on other missions. By repainting on this frequent of a basis, more chemicals are used and more waste is generated.

1.1 Test Objectives

The objective of the proposed VCPI demonstration is to collect operational and performance data to validate to the proper DoD decision makers that this technology works well to visually indicate surface contamination and is a feasible technology to insert into ‘real-world’ operations. The results of this effort will be documented and distributed to other DoD facilities that have a need to have surfaces free-from-contamination prior to proceeding to other corrosion prevention and control processes.

Specifically, the test objectives for this investigation are as follows:

1. Illustrate that VCPI dyes are capable of visually labeling surface contamination, which promotes for a more effective surface cleaning operation
2. Demonstrate that VCPI application is feasible in production maintenance facilities responsible for processing military equipment
3. Document potential applicability for multiple applications
4. Document manpower, material, and environmental benefits associated with process implementation

Information about the VCPI technology is summarized below:

1. VCPI is a technology that can be chemically customized to selectively bind with specific surface contaminants found on the surfaces of military equipment. By using a dye solution that chemically binds with contamination, this labeling process will provide a “real time” visual indication to maintenance personnel where surface contamination still resides and cleaning operations need to be focused (ref. Figure A1).

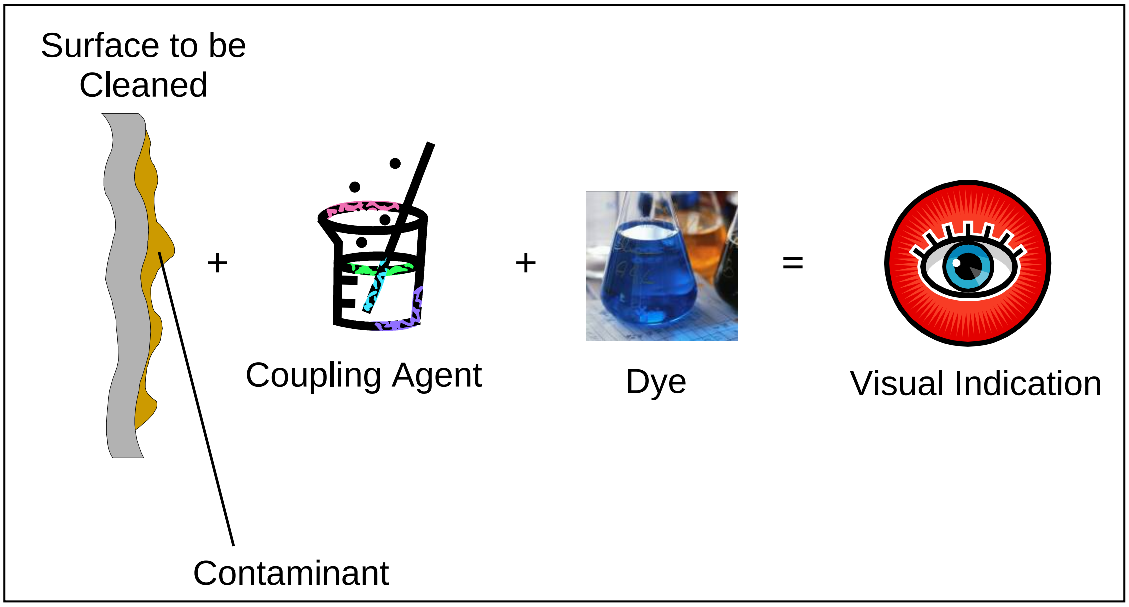


Figure A13. VCPI Technology

2. For the subject study, the VCPI dye formulations selected for each production site will vary slightly. The formulation chosen for the Mayport Naval Station (MNS) demonstration will be selected to indicate salt contamination found on coated ship hulls. Salt will mark sea spray, become ingrained in oil and grease contamination, and is a large component of bio-based materials that adhere to the sides of the hull. These contaminants are difficult to see, and will adversely influence the adhesion properties of the coating system applied to the surfaces of the hulls. By marking salt contaminants and biofilms, the VCPI dye will identify where contamination resides on the surface of the ship. At Hill AFB, a VCPI dye solution will be formulated to indicate oil, grease, and hydraulic fluid contamination on aircraft. At the latter maintenance facility, oil and grease contamination is of the greatest concern for adequate adhesion of protective coatings that serve as the primary corrosion protection system.
3. The VCPI technology was first developed through a SERDP initiative (HECSA Contract No. DACA 72-99-C-0005, Items 0001, 0002, 0003, and 0004). For further information on this project, please refer to the final report, issued by Battelle on 15 March 2002. This report can be downloaded directly from the SERDP website, located at http://docs.serdp-estcp.org/index.cfm.
4. The demonstrations at Hill AFB, and the Mayport Naval Station will be the first full field demonstrations of the VCPI technology.

2.0 Pre-Demonstration Laboratory Analysis

2.1 Formulation Work

Hill AFB Test Platform - VCPI Test Solution No. 1. Results obtained from the laboratory testing phase of this program will be measured by visual as well as analytical testing. This testing will confirm an ability to label specific contaminants in as short a contact dwell time as 30 seconds, with water rinsing occurring for up to 45 seconds in one location. The goal from all rinsing operations will be to not affect the labeling potential of the respective dye solutions. The labeling agents must be freely removed from the clean surfaces with water rinsing which then reveals the contaminant.

Preliminary laboratory experiments have identified that 12,000 ppm of Oil Red "O" blended with 0.5% Kelzan (Xanthan gum) provides adequate labeling of three major contaminants identified during the baselining activity; MIL-H-83282 (hydraulic oil), MIL-L-23699 (lube oil) and Mobil Grease. In identifying the concentration of dye and Xanthan gum concentrations all three contaminants were utilized, while only the MIL-H-83282 was used in the statistical test plan that was designed to support the chemistry for the Air Force dye solution. B&B Re-Gel was reviewed as a possible dye carrier, but was found to remove the contaminants, even when the concentrations were reduced to 1:4 Re-Gel to Water.

For the statistical test plan 12,000ppm of Oil Red "O" was made by dissolving 12 gms into 120 ml of isopropyl alcohol and then adding to the prepared mixture into 1L of a 0.5% Xanthan gum and water solution. The Xanthan gum was prepared by adding 5 gms of Kelzan slowly to an Erlenmeyer on a stir plate containing 1L of deionized water (DI-H_2O), which temperature has been raised to between 35 and 45 degrees C.

A set of 3"x5" Al2024 test panels used to support the statistical test plan were identified by scribing a reference "LRB" number on the opposite side of surfaces being contaminated and labeled. Each panel was thoroughly cleaned by using the following procedure referenced from T.O. 1F-16C-23, Section 1-63 "Refinishing Procedures for FMS-3029 Corrosion Protective Layer Exterior Surfaces":

1. Rinse panels with DI-H_2O
2. Spray B&B ReGel onto the surface, then lightly sand with 240 grit sanding disk (3M 265L). This step was added to remove any surface contaminants from handling of the test coupons
3. Rinse with DI-H_2O
4. Apply PreKote, followed by lightly sanding using 180 grit sanding disk (3M-7447)
5. Rinse with DI-H_2O
6. Suspend from the test racks to air dry in the vertical position
7. Ready for testing

The results and test panel matrix for the Air Force platform and corresponding VCPI test solution is provided in Table A-1.

Table A-1. VCPI-USAF Panel Test Plan Used to Optimize the Labeling of Contaminants by Varying the Contact Dwell Time to DI-water Rinse Times

	Run	Block	Dwell Time	Rinse Time
Panel LRB#	#	#	(min)	(sec)
51273-16-6	1	1	7.75	30
51273-16-5	2	1	7.75	30
51273-16-14	3	1	15	15
51273-16-4	4	1	15	15
51273-16-3	5	1	7.75	30
51273-16-22	6	1	15	45
51273-16-34	7	1	0.5	45
51273-16-27	8	1	15	45
51273-16-9	9	1	0.5	15
51273-16-2	10	1	15	45
51273-16-25	11	1	0.5	15
51273-16-15	12	1	0.5	45
51273-16-10	13	1	15	15
51273-16-19	14	1	0.5	45
51273-16-20	15	1	0.5	15

Panels we're arranged in sets of three suspended in the rinse fixture shown in Figure A2 to facilitate the testing protocol as given in the preceding table. As detailed in Figure A2, a full set of panels are loaded and ready for testing.

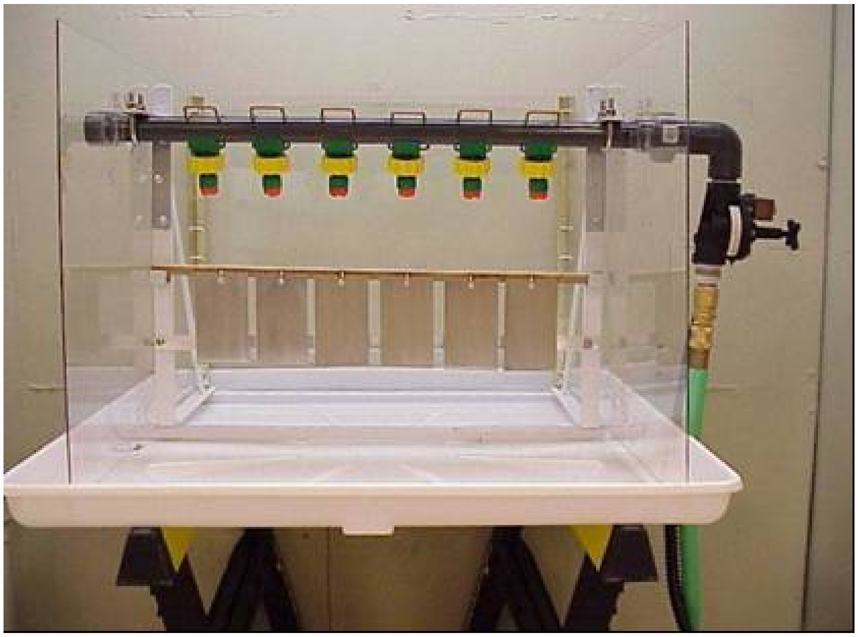


Figure A2. Laboratory Test Panel Water Rinsing Station

To ensure a soft rinsing action, the rinse fixture utilizes a flat plane nozzle to rinse the panels from the top flowing down over the surface of the panel. Water flow is controlled by an on/off toggle switch wired to a pressure controlled solenoid valve. Water flow was able to be timed and pressure controlled for repeatability required for testing.

Prior to labeling and rinsing, all test panels were weighed on an analytical balance to the nearest 0.0001 grams as a means of recording the clean weights. Panels were also measured as a function of DataColor L*a*b* values.

Application of the VCPI dye solution was accomplished by spray application using the DeVilbiss EXL-520S HVLP suction feed spray gun, with a gun inlet pressure of 30 psi. Once the gun was set no changes were made. The panels were pre-rinsed with water to simulate the surface rinsing that they would see at the prep facility. The surfaces of the panels were then sprayed until wet, with the timer started for Contact Dwell Time. Figure A3 documents an example of the surface of three panels after a spray coating of the 0.5% Xanthan gum with 12,000 ppm ORO mixture selected for the Air Force VCPI Dem/Val test.

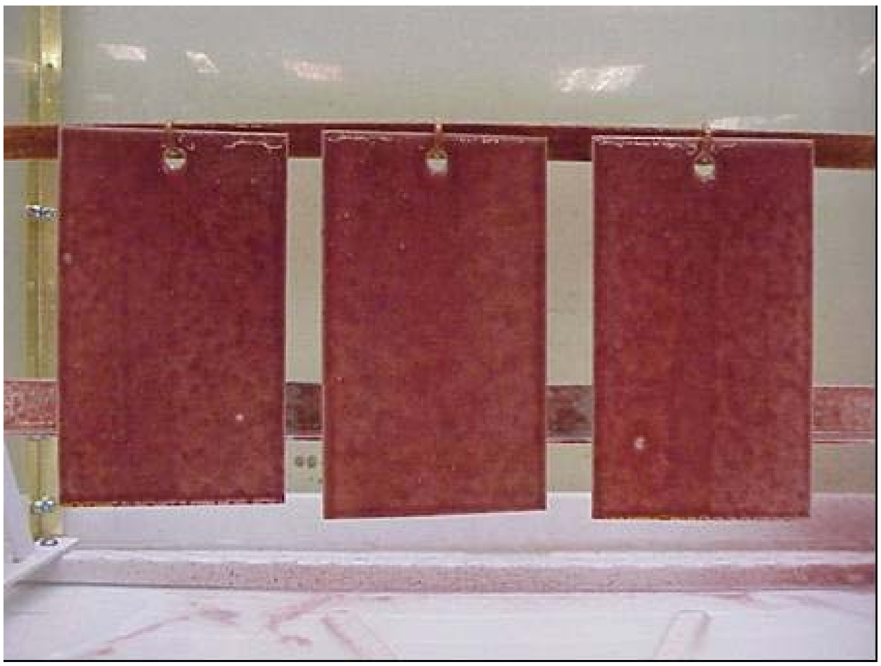


Figure A3. Laboratory Test Panels after Oil RedO Labeling

At the end of the designated Contact Dwell Time, the water rinse was commenced for the duration prescribed in the test plan shown in Table 1. The panels were then removed and placed on a vertical drying rack similar to the rod above to air dry. Once dry they were weighed for residual contaminant/label data, as well as performing Light Box analysis using Daylight, Incandescent and Cool White Fluorescence lighting. In addition the DataColor L*a*b* measurements were taken to determine the absolute value for labeling. A summary of the results obtained from the initial laboratory investigations is provided in Table A-2.

Table A-2. Statistical Test Results for Air Force Base VCPI Dye Solution

					Test Coupon Data				
			Contaminant				Net	Post	Residual
	Run	Block	Dwell Time	Rinse Time	Clean Wt.	Contam. Wt.	Contam. Wt.	Labeling Rinse Wt.	Contam. + Label Wt.
Panel LRB#	#	#	(min)	(sec)	(gms)	(gms)	(gms)	(gms)	(gms)
51273-16-14	3	1	15	15	21.6729	21.7092	0.0363	21.6793	0.0064
51273-16-4	4	1	15	15	21.6659	21.7187	0.0528	21.6719	0.0060
51273-16-10	13	1	15	15	21.6242	21.6733	0.0491	21.6279	0.0037
						Average:	0.0461		0.0054
51273-16-6	1	1	7.75	30	21.6725	21.7188	0.0463	21.6749	0.0024
51273-16-5	2	1	7.75	30	21.6850	21.7204	0.0354	21.6901	0.0051
51273-16-3	5	1	7.75	30	21.5577	21.5945	0.0368	21.5614	0.0037
						Average:	0.0395		0.0037
51273-16-9	9	1	0.5	15	21.6143	21.6437	0.0294	21.6179	0.0036
51273-16-25	11	1	0.5	15	21.8098	21.8496	0.0398	21.8150	0.0052
51273-16-20	15	1	0.5	15	21.7117	21.7758	0.0641	21.7149	0.0032
						Average:	0.0444		0.0040
51273-16-34	7	1	0.5	45	21.6794	21.7296	0.0502	21.6859	0.0065
51273-16-15	12	1	0.5	45	21.5767	21.6228	0.0461	21.5796	0.0029
51273-16-19	14	1	0.5	45	21.5112	21.5631	0.0519	21.5151	0.0039
						Average:	0.0494		0.0044
51273-16-22	6	1	15	45	21.6758	21.7234	0.0476	21.6806	0.0048
51273-16-27	8	1	15	45	21.7118	21.7530	0.0412	21.7163	0.0045
51273-16-2	10	1	15	45	21.6909	21.7525	0.0616	21.6962	0.0053
						Average:	0.0501		0.0049
	Average Contamination Weight to each Panel:						0.0459		
		Average Residual Contamination/Labling Weight on each Panel:							0.0045
			Average Contamination/Labling Weight Lost from Rinsing:						90.2%

The information summarized in Table A-3 serves to document the relevant test conditions used for each of the test panels that are depicted in Figures A4, A5, and A6. As shown, the photographs characterize the visual perception differences for the VCPI dye solution applied to surfaces of the test panels as a function of three different lighting conditions.

Table A-3. Light Box Identification Code for Test Panels Labeled with HAFB VCPI Dye

				Run# 9 Dwell 0.5 min Rinse 15 sec 51273-16-9	Run# 11 Dwell 0.5 min Rinse 15 sec 51273-16-25	Run# 15 Dwell 0.5 min Rinse 15 sec 51273-16-20
Run# 3 Dwell 15min Rinse 15 sec 51273-16-14	Run# 4 Dwell 15min Rinse 15 sec 51273-16-4	Run# 13 Dwell 15min Rinse 15 sec 51273-16-10	CLEAN PANEL	Run# 7 Dwell 0.5 min Rinse 45 sec 51273-16-34	Run# 12 Dwell 0.5 min Rinse 45 sec 51273-16-15	Run# 14 Dwell 0.5 min Rinse 45 sec 51273-16-19
Run# 1 Dwell 7.75min Rinse 30 sec 51273-16-6	Run# 2 Dwell 7.75min Rinse 30 sec 51273-16-5	Run# 5 Dwell 7.75min Rinse 30 sec 51273-16-3	CLEAN PANEL	Run# 34 Dwell 15 min Rinse 45 sec 51273-16-22	Run# 15 Dwell 15 min Rinse 45 sec 51273-16-27	Run# 19 Dwell 15 min Rinse 45 sec 51273-16-2

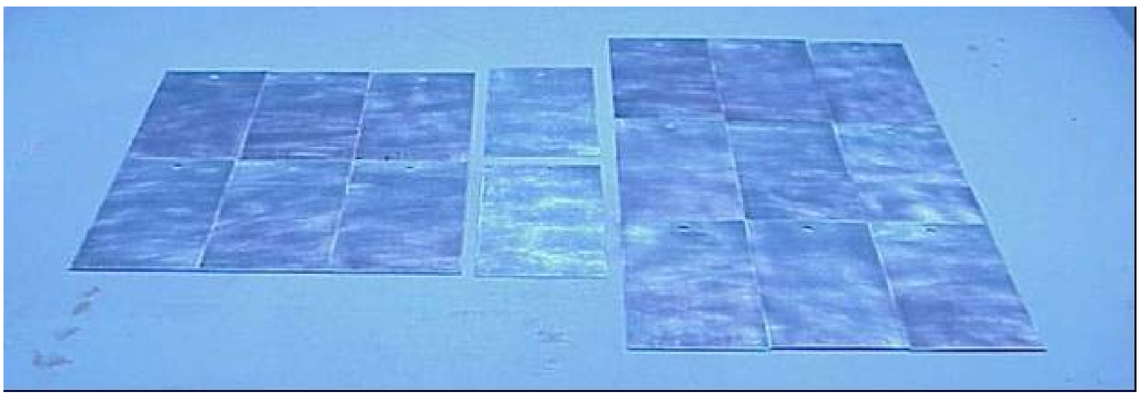


Figure A4. Light Box Photograph Documenting VCPI Dye Solution with Daylight Lamps

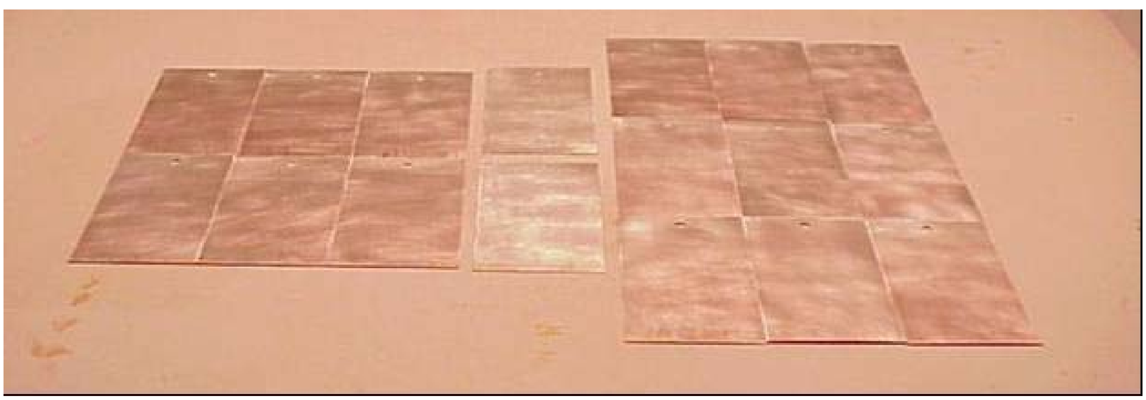


Figure A5. Light Box Photograph Documenting VCPI Dye Solution with Incandescent Lamps

Figure A6. Light Box Photograph Documenting VCPI Dye Solution with Cool White Fluorescent Lamps

The information summarized in Table A-4 provides a summary of the light box data collected for the test panels labeled with the Air Force VCPI dye solution. This laboratory testing exercise was designed to optimize the dwell time for the respective dye solutions on the surfaces of the test panels. All testing was completed for the hydraulic fluid contaminant, which was considered to be the most severe and common contaminant on the surfaces of the A-10 aircraft.

Table A-5 summarizes the DataColor data collected from the various laboratory test panels coated with the Air Force VCPI dye solution. As with the visual inspection data collected from the three lighting conditions, this information serves to quantify an optimal dwell and rinse time for the dye solution, as a function of color intensity.

Table A-4. Results from Light Box Testing Conducted on Air Force VCPI Dye Solution

					Light Box Source Rating (5=Clean, 1=Contam.)		
Panel LRB#	Run #	Block #	Dwell Time (min)	Rinse Time (sec)	Cool White Flourescence (5-1)	Daylight (5-1)	Incandescent (5-1)
51273-16-14	3	1	15	15	1	1	1
51273-16-4	4	1	15	15	1	1	1
51273-16-10	13	1	15	15	1	1	2
				Average:	1.00	1.00	1.33
51273-16-6	1	1	7.75	30	1	1	1
51273-16-5	2	1	7.75	30	1	1	2
51273-16-3	5	1	7.75	30	1	1	2
				Average:	1.00	1.00	1.67
51273-16-9	9	1	0.5	15	1	1	1
51273-16-25	11	1	0.5	15	1	1	1
51273-16-20	15	1	0.5	15	1	2	1
				Average:	1.00	1.33	1.00
51273-16-34	7	1	0.5	45	2	2	2
51273-16-15	12	1	0.5	45	2	2	1
51273-16-19	14	1	0.5	45	2	2	2
				Average:	2.00	2.00	1.67
51273-16-22	6	1	15	45	2	2	2
51273-16-27	8	1	15	45	2	2	1
51273-16-2	10	1	15	45	1	2	1
				Average:	1.67	2.00	1.33

			Average		
Block #	Dwell Time (min)	Rinse Time (sec)	Cool White Flourescence (5-1)	Daylight (5-1)	Incandescent (5-1)
1	0.5	15	1.00	1.33	1.00
1	0.5	45	2.00	2.00	1.67
1	7.75	30	1.00	1.00	1.67
1	15	15	1.00	1.00	1.33
1	15	45	1.67	2.00	1.33

Table A-5. Results from Data Color Measurements Collected from Test Panels Coated with Air Force VCPI Dye Solution

					Data Color Measurement						
	Run	Block	Dwell Time	Rinse Time	L*		a*			b*	
Panel LRB#	#	#	(min)	(sec)	Clean	Labeled	Clean	Labeled	% Chg.	Clean	Labeled
51273-16-14	3	1	15	15	84.31	76.70	0.11	3.83	97.1%	2.52	2.21
51273-16-04	4	1	15	15	84.32	75.72	0.15	4.90	96.9%	2.53	2.80
51273-16-10	13	1	15	15	86.60	78.31	0.05	2.94	98.3%	1.84	1.91
				Average:	85.08	76.91	0.10	3.89	97.5%	2.30	2.31
51273-16-6	1	1	7.75	30	83.87	77.46	0.20	3.30	93.9%	2.97	2.15
51273-16-5	2	1	7.75	30	83.61	76.10	0.23	4.60	95.0%	3.14	2.46
51273-16-3	5	1	7.75	30	83.52	75.35	0.24	3.18	92.5%	3.06	2.75
				Average:	83.67	76.30	0.22	3.69	93.8%	3.06	2.45
51273-16-09	9	1	0.5	15	83.84	76.06	0.21	4.04	94.8%	3.03	2.58
51273-16-25	11	1	0.5	15	88.00	79.64	-0.16	4.67	103.4%	0.77	0.56
51273-16-20	15	1	0.5	15	86.28	77.34	0.07	3.17	97.8%	2.09	2.04
				Average:	86.04	77.68	0.04	3.96	98.7%	1.96	1.73
51273-16-34	7	1	0.5	45	88.52	79.07	-0.17	5.39	103.2%	0.59	0.92
51273-16-15	12	1	0.5	45	83.30	77.86	0.20	2.88	93.1%	3.07	1.80
51273-16-19	14	1	0.5	45	86.86	79.04	0.06	3.57	98.3%	1.79	1.53
				Average:	86.23	78.66	0.03	3.95	98.2%	1.82	1.42
51273-16-22	6	1	15	45	85.49	75.37	0.13	4.70	97.2%	2.34	2.70
51273-16-27	8	1	15	45	87.31	79.66	-0.17	3.87	104.4%	0.89	0.73
51273-16-02	10	1	15	45	84.00	74.30	0.21	4.26	95.1%	2.81	2.97
				Average:	85.60	76.44	0.06	4.28	98.9%	2.01	2.13

L, L=0 yields black and L=100 indicates white
a, negative values indicate green while positive values indicate red and its position between yellow and blue
b, negative values indicate blue and positive values indicate yellow

Data Color Measurement				
Block	Dwell Time	Rinse Time	L	
#	(min)	(sec)	Clean	Labeled
1	0.5	15	86.04	77.68
1	0.5	45	86.04	77.68
1	15	15	85.08	76.91
1	15	45	85.60	76.44

An additional set of laboratory tests were also conducted on a section of the upper wing of an F-16 aircraft that has gone through numerous cleaning, refinishing, painting, and depainting cycles. The surfaces of the wing section evaluated during this investigation had been stripped with a Type V dry media prior to being supplied to Battelle. The only pre-test processing completed on this component included an MEK solvent wipe.

Mayport Naval Station Test Platform - VCPI Test Solution No. 2. A baselining visit to the Mayport Naval Station, and information collected directly from Dr. Scott Sirchio POC for this Dem/Val test platform), confirmed that the primary target contaminants of the surfaces of Navy ship hulls were water soluble salts and biofilms. Previous testing completed during the SERDP program identified two dyes that are capable of effectively labeling these contaminants. The dye selected for this platform, based on the dispersion rates in sea water, was Fast Green "FCF", CAS No. 2353-45-9. This dye was also selected for its ability to selectively label panels, without staining the painted surfaces of steel test panels. A 500 ppm concentration of FCF and a 0.5% solution of Xanthan Gum (Kelsan) and DI-Water was formulated to be the carrier.

Two sets of 15 painted FEHY-80 steel test panels were evaluated during the laboratory phase of this investigation. All surfaces of the individual panels were prepared and then coated in accordance with the materials and procedures specified in the Naval Ships Technical Manual S9086-VD-STM-020/CH-631V2R1, Chapter 631, Volume 2. For testing purposes, the surfaces of one set of panels were not contaminated and were referenced as test control panels. The surfaces on the second set of panels were spray coated with a thin film of Atlantic Sea Water, and these panels were considered the experimental set. Table 6 documents the test panel matrix as a function of the dye dwell time, rinse time, and detection limits.

As with the Air Force laboratory evaluations, the following three test methods were used to evaluate the surfaces of the panels; delta weight measurements, visual inspection and photographic documentation, as well as Datacolor. No color light box assessments were conducted during the laboratory assessment because the human visual detection limits were unable to discern significant differences between the various light sources. In order to expedite the testing and provide visual comparisons, the contaminated panels were labeled side by side with bare painted panels. This approach provided the most obvious visual benefits.

Visually, the difference was dramatic in how the FCF was able to highlight the difference between salt contaminated panels and painted only panels. The labeling patterns and dispersion characteristics of the VCPI dye solution on the two sets of panels was noticeable different, with a color on salt nearing purple in appearance. By contrast, any labeling of the surfaces of the painted control panels resulted in only a green appearance.

All results obtained from the laboratory tests completed on the painted and VCPI labeled test panels without contamination and with sea salt contamination are provided in Tables A-7 and A-8, and Tables A-9 and A-10, respectively. As shown, the results of the measured weight differences on bare non-contaminated painted test panels reflect a 0.002 – 0.005% increase in weight, well within the measurement error for this method. By comparison, the panels that had been contaminated had a 0.006 – 0.010% increase in weight from clean. This result confirms that some of the residual salts attached to the surfaces of the panels after a water rinsing. However, it should be noted that approximately 2 percent of the salts applied to these panels was rinsed away with the labeling process. This is a good result from the standpoint that the label and dye were removed with a thorough rinsing operation. The data referenced in the following text confirms that dye dwell time and water rinse times are negligible in affecting the efficiency of the VCPI labeling process.

Datacolor results for "painted-only" panels suggest that residence times less than 7.45 minutes measured slightly better in percent color change from baseline for a* and b*, with L* being neutral to change. Contaminated panels produced similar results for a* and L*, but b* at 15 second dwell and 15 second rinse recorded a 2.11% change from clean. The differences all in all are very low.

A series of color photographs documenting the visual results obtained from this series of laboratory tests are provided for review in the following text.

VCPI-NAVY
FEHY80 Painted Panels
Atlantic Sea Water Contaminated vs Bare Paint

Label Dwell Time: 15 minutes
Water Rinse Time: 15 seconds

51273-7-2 Salt	51273-6-26	51273-6-29 Salt	51273-7.6	51273-6-30 Salt	51273-7-12

Panels immediately after labeling.

Panels at the end of the label dwell time.

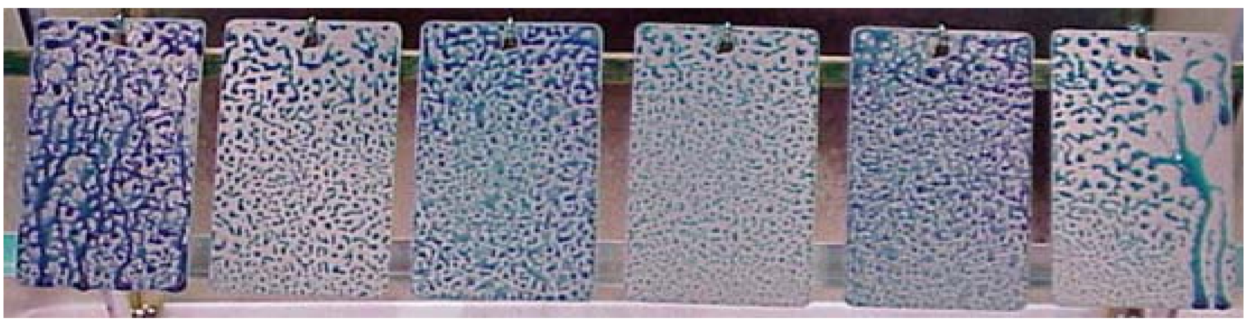
Panels post water rinsed.

VCPI-NAVY
FEHY80 Painted Panels
Atlantic Sea Water Contaminated vs Bare Paint

Label Dwell Time: 15 minutes
Water Rinse Time: 45 seconds

51273-7-12 Salt	51273-7-11	51273-7-5 Salt	51273-7-4	51273-7-28 Salt	51273-6-11

Panels immediately after labeling.



Panels at the end of the label dwell time.

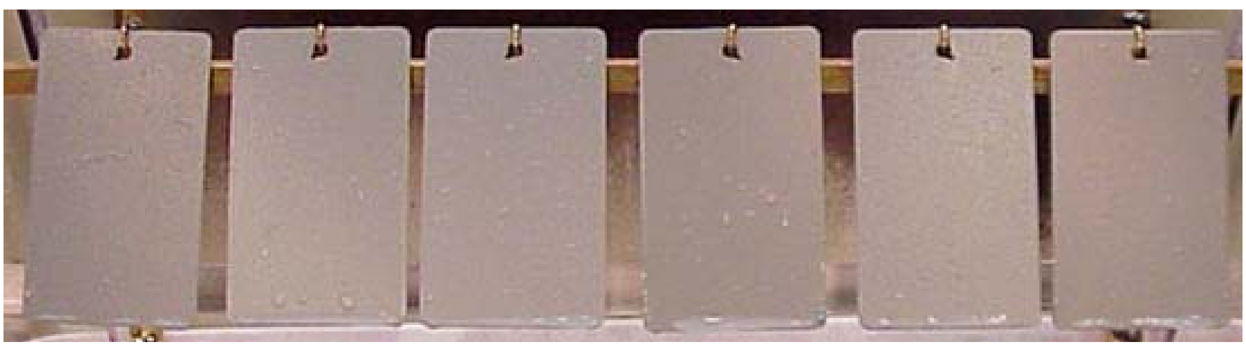
Panels post water rinsed.

VCPI-NAVY
FEHY80 Painted Panels
Atlantic Sea Water Contaminated vs Bare Paint

Label Dwell Time: 0.5 minutes
Water Rinse Time: 45 seconds

51273-7-14 Salt	51273-7-10	51273-7-15 Salt	51273-6-16	51273-7-19 Salt	51273-6-14

Panels immediately after labeling.

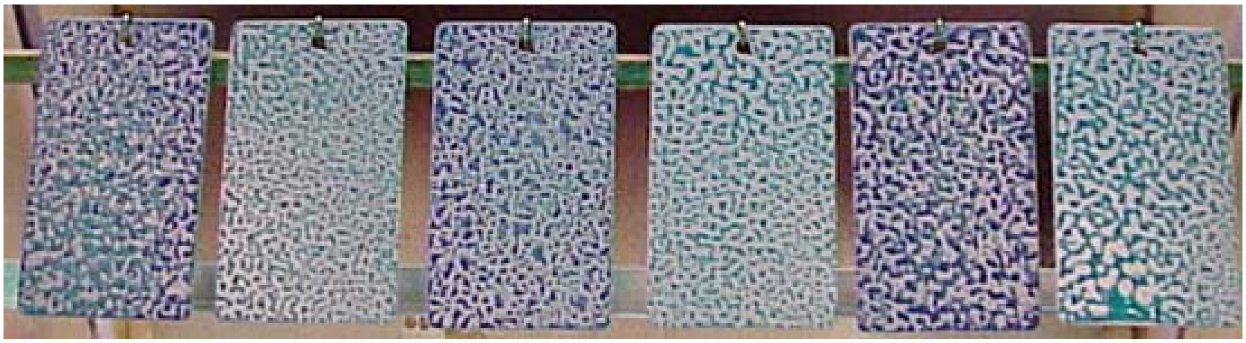


Panels post water rinsed.

VCPI-NAVY
FEHY80 Painted Panels
Atlantic Sea Water Contaminated vs Bare Paint

Label Dwell Time: 0.5 minutes
Water Rinse Time: 15 seconds

51273-6-22	51273-6-3	51273-6-13	51273-6-6	51273-6-12	51273-6-7
Salt		Salt		Salt	



Panels immediately after labeling.

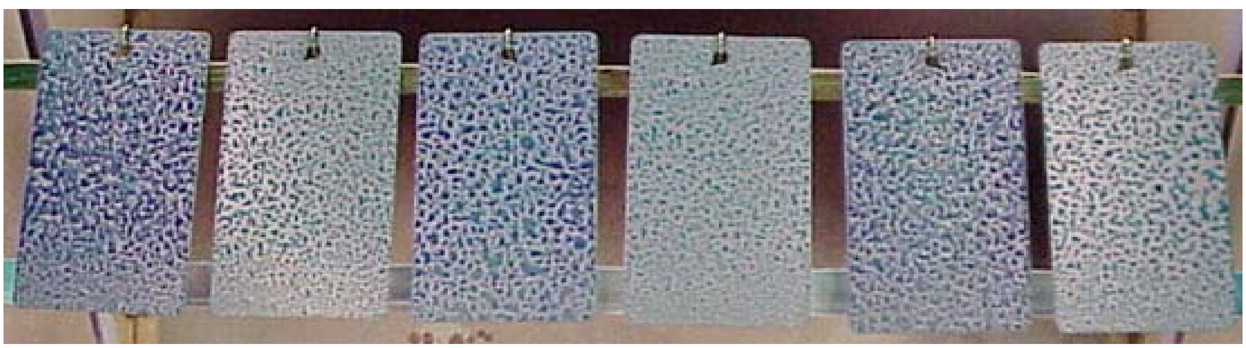
Panels post water rinsed.

VCPI-NAVY
FEHY80 Painted Panels
Atlantic Sea Water Contaminated vs Bare Paint

Label Dwell Time: 7.75 minutes
Water Rinse Time: 30 seconds

51273-6-27	**51273-7-7**	**51273-6-8**	**51273-6-32**	**51273-6-21**	**51273-7-3**
Salt		**Salt**		**Salt**	

Panels immediately after labeling.



Panels at the end of the label dwell time.

Panels post water rinsed.

Table A-6. Navy-VCPI Test Panel Matrix

Panel LRB#	Run #	Block #	Dwell Time (min)	Rinse Time (sec)
51273-6-27	1	5	7.75	30
51273-6-8	2	5	7.75	30
51273-7-2	3	5	15	15
51273-6-29	4	5	15	15
51273-6-21	5	5	7.75	30
51273-7-12	6	5	15	45
51273-7-14	7	5	0.5	45
51273-7-5	8	5	15	45
51273-6-22	9	5	0.5	15
51273-6-28	10	5	15	45
51273-6-13	11	5	0.5	15
51273-7-15	12	5	0.5	45
51273-6-30	13	5	15	15
51273-6-19	14	5	0.5	45
51273-6-12	15	5	0.5	15

VCPI - NAVY Test Matrix with no Contamiants

Panel LRB#	Run #	Block #	Labeling Dwell Time (min)	Water Rinse Time (sec)
71273-7-7	1	4	7.75	30
71273-6-32	2	4	7.75	30
71273-6-26	3	4	15	15
71273-7-6	4	4	15	15
71273-7-3	5	4	7.75	30
71273-7-11	6	4	15	45
71273-7-10	7	4	0.5	45
71273-7-4	8	4	15	45
71273-6-3	9	4	0.5	15
71273-6-11	10	4	15	45
71273-6-6	11	4	0.5	15
71273-6-16	12	4	0.5	45
71273-7-12	13	4	15	15
71273-6-14	14	4	0.5	45
71273-6-7	15	4	0.5	15

Table A-7. Panel Weight Measurements for Coated Steel Test Panels With no Contaminants

Panel LRB#	Run #	Block #	Dwell Time (min)	Rinse Time (sec)	Clean Panel Wt. (gms)	Panel Wt. after Labeling & Rinsing (gms)	Net Residual Panel Wt. (gms)	Wt. Change from %
71273-6-26	3	4	15	15	64.1501	64.1521	0.0020	0.003%
71273-7-6	4	4	15	15	64.2341	64.2347	0.0006	0.001%
71273-7-12	13	4	15	15	64.7908	64.7924	0.0016	0.002%
						Average:	**0.0014**	**0.002%**
71273-7-7	1	4	7.75	30	64.5697	64.5745	0.0048	0.007%
71273-6-32	2	4	7.75	30	64.2233	64.2261	0.0028	0.004%
71273-7-3	5	4	7.75	30	64.3183	64.3204	0.0021	0.003%
						Average:	**0.0032**	**0.005%**
71273-6-3	9	4	0.5	15	64.1082	64.1096	0.0014	0.002%
71273-6-6	11	4	0.5	15	64.1156	64.1169	0.0013	0.002%
71273-6-7	15	4	0.5	15	64.3511	64.3520	0.0009	0.001%
						Average:	**0.0012**	**0.002%**
71273-7-10	7	4	0.5	45	64.4635	64.4664	0.0029	0.004%
71273-6-16	12	4	0.5	45	64.3155	64.3181	0.0026	0.004%
71273-6-14	14	4	0.5	45	64.4205	64.4221	0.0016	0.002%
						Average:	**0.0024**	**0.004%**
71273-7-11	6	4	15	45	64.3249	64.3271	0.0022	0.003%
71273-7-4	8	4	15	45	63.8938	63.8947	0.0009	0.001%
71273-6-11	10	4	15	45	63.9499	63.9517	0.0018	0.003%
						Average:	**0.0016**	**0.003%**

Average Clean Panel Weight:	64.2820
Average Net Panel Weight Change at the end of testing:	0.0020

Table A-8. Results of DataColor Measurements Collected for Test Panels Coated with no Contaminants and VCPI-Navy Dye Solution

	Data Color Measurement												
	Run	Block	Dwell Time	Rinse Time	L*			a*			b*		
Panel LRB#	#	#	(min)	(sec)	Panel Clean	Panel Post Labeling	% Change from Clean	Panel Clean	Panel Post Labeling	% Change from Clean	Panel Clean	Panel Post Labeling	% Change from Clean
71273-6-26	3	3	15	15	58.24	58.17	-0.12%	-2.17	-2.19	0.91%	-3.39	-3.39	0.00%
71273-7-6	4	3	15	15	58.25	58.17	-0.14%	-2.19	-2.20	0.45%	-3.36	-3.39	0.89%
71273-7-12	13	3	15	15	58.29	58.19	-0.17%	-2.18	-2.20	0.91%	-3.37	-3.38	0.30%
				Average:	58.26	58.18	**-0.14%**	-2.18	-2.20	**0.76%**	-3.37	-3.39	**0.40%**
71273-7-7	1	3	7.75	30	58.37	58.28	-0.15%	-2.18	-2.19	0.46%	-3.34	-3.39	1.50%
71273-6-32	2	3	7.75	30	58.31	58.22	-0.15%	-2.19	-2.19	0.00%	-3.34	-3.39	1.50%
71273-7-3	5	3	7.75	30	58.28	58.22	-0.10%	-2.19	-2.18	-0.46%	-3.36	-3.42	1.79%
				Average:	58.32	58.24	**-0.14%**	-2.19	-2.19	**0.00%**	-3.35	-3.40	**1.59%**
71273-6-3	9	3	0.5	15	58.26	58.21	-0.09%	-2.19	-2.20	0.45%	-3.38	-3.42	1.18%
71273-6-6	11	3	0.5	15	58.29	58.22	-0.12%	-2.18	-2.19	0.46%	-3.38	-3.41	0.89%
71273-6-7	15	3	0.5	15	58.33	58.24	-0.15%	-2.19	-2.18	-0.46%	-3.31	-3.32	0.30%
				Average:	58.29	58.22	**-0.12%**	-2.19	-2.19	**0.15%**	-3.36	-3.38	**0.79%**
71273-7-10	7	3	0.5	45	58.27	58.23	-0.07%	-2.18	-2.19	0.46%	-3.38	-3.40	0.59%
71273-6-16	12	3	0.5	45	58.30	58.25	-0.09%	-2.20	-2.18	-0.92%	-3.40	-3.46	1.76%
71273-6-14	14	3	0.5	45	58.29	58.24	-0.09%	-2.20	-2.21	0.45%	-3.37	-3.38	0.30%
				Average:	58.29	58.24	**-0.08%**	-2.19	-2.19	**0.00%**	-3.38	-3.41	**0.88%**
71273-7-11	6	3	15	45	58.31	58.20	-0.19%	-2.16	-2.23	3.14%	-3.36	-3.39	0.89%
71273-7-4	8	3	15	45	58.28	58.18	-0.17%	-2.20	-2.19	-0.46%	-3.35	-3.42	2.09%
71273-6-11	10	3	15	45	58.25	58.19	-0.10%	-2.17	-2.20	1.36%	-3.40	-3.41	0.29%
				Average:	58.28	58.19	**-0.15%**	-2.18	-2.21	**1.35%**	-3.37	-3.41	**1.09%**

L, L=0 yields black and L=100 indicates white
a, negative values indicate green while positive values indicate red and its position between yellow and blue
b, negative values indicate blue and positive values indicate yellow

Table A-9. Panel Weight Measurements for Test Panels Coated with Contaminants and VCPI-Navy Dye Solution

Panel LRB#	Run #	Block #	Dwell Time (min)	Rinse Time (sec)	Clean Panel Wt. (gms)	Panel Wt. After Additon of Contaminant (gms)	Net Contaminant Addition (gms)	Panel Wt. after Labeling & Rinsing (gms)	Net Residual Panel Wt. Difference (gms)	Resultant Wt. Change from Clean %
51273-7-2	3	5	15	15	63.9616	64.1585	0.1969	63.9660	0.0044	0.007%
51273-6-29	4	5	15	15	63.5981	63.8107	0.2126	63.6020	0.0039	0.006%
51273-6-30	13	5	15	15	64.0241	64.2470	0.2229	64.0267	0.0026	0.004%
				Average:	63.8613	64.0721	**0.2108**		**0.0036**	
						Average % Change:	**0.33%**			**0.006%**
									Percent of Contaminant Removal:	**-98.3%**
51273-6-27	1	5	7.75	30	64.2344	64.4089	0.1745	64.2367	0.0023	0.004%
51273-6-8	2	5	7.75	30	63.9845	64.2341	0.2496	63.9879	0.0034	0.005%
51273-6-21	5	5	7.75	30	63.8875	64.1145	0.2270	63.8965	0.0090	0.014%
				Average:	64.0355	64.2525	**0.2170**		**0.0049**	
						Average % Change:	**0.34%**			**0.008%**
									Percent of Contaminant Removal:	**-97.7%**
51273-6-22	9	5	0.5	15	64.2798	64.4470	0.1672	64.2846	0.0048	0.007%
51273-6-13	11	5	0.5	15	63.8506	64.0577	0.2071	63.8561	0.0055	0.009%
51273-6-12	15	5	0.5	15	64.0033	64.3715	0.3682	64.0126	0.0093	0.015%
				Average:	64.0446	64.2921	**0.2475**		**0.0065**	
						Average % Change:	**0.39%**			**0.010%**
									Percent of Contaminant Removal:	**-97.4%**
51273-7-14	7	5	0.5	45	64.0513	64.2310	0.1797	64.0539	0.0026	0.004%
51273-7-15	12	5	0.5	45	63.8352	64.0390	0.2038	63.8396	0.0044	0.007%
51273-6-19	14	5	0.5	45	64.1304	64.3655	0.2351	64.1345	0.0041	0.006%
				Average:	64.0056	64.2118	**0.2062**		**0.0037**	
						Average % Change:	**0.32%**			**0.006%**
									Percent of Contaminant Removal:	**-98.2%**
51273-6-12	6	5	15	45	64.1049	64.2739	0.1690	64.1091	0.0042	0.007%
51273-7-5	8	5	15	45	64.0149	64.2284	0.2135	64.0191	0.0042	0.007%
51273-6-28	10	5	15	45	63.8908	64.1191	0.2283	63.8960	0.0052	0.008%
				Average:	64.0035	64.2071	**0.2036**		**0.0045**	
						Average % Change:	**0.32%**			**0.007%**
									Percent of Contaminant Removal:	**-97.8%**
				Average Clean Panel Weight:	63.9894					
						Average Weight of Contaminants A	0.2170			
								Average Net Panel Weight Change at the end of testing:	0.0047	

Table A-10. Results of DataColor Measurements Collected for Test Panels Coated with Contaminants and VCPI-Navy Dye Solution

	Data Color Measurement															
	Run	Block	Dwell Time	Rinse Time	L*				a*				b*			
Panel LRB#	#	#	(min)	(sec)	Panel Clean	Panel Post Contamination	Panel Post Labeling	% Change from Clean	Panel Clean	Panel Post Contamination	Panel Post Labeling	% Change from Clean	Panel Clean	Panel Post Contamination	Panel Post Labeling	% Change from Clean
51273-7-2	3	5	15	15	58.27	60.86	58.12	-0.26%	-2.18	-1.95	-2.29	5.05%	-3.40	-2.46	-3.42	0.59%
51273-6-29	4	5	15	15	58.29	60.68	58.11	-0.31%	-2.17	-1.87	-2.25	3.69%	-3.35	-2.48	-3.41	1.79%
51273-6-30	13	5	15	15	58.33	60.78	58.09	-0.41%	-2.16	-1.85	-2.20	1.85%	-3.37	-2.46	-3.42	1.48%
				Average:	58.30	60.77	58.11	**-0.33%**	-2.17	-1.89	-2.25	**3.53%**	-3.37	-2.47	-3.42	**1.29%**
51273-6-27	1	5	7.75	30	58.28	60.86	58.11	-0.29%	-2.16	-1.96	-2.18	0.93%	-3.35	-2.47	-3.41	1.79%
51273-6-8	2	5	7.75	30	58.27	60.90	58.04	-0.39%	-2.18	-1.91	-2.29	5.05%	-3.36	-2.64	-3.42	1.79%
51273-6-21	5	5	7.75	30	58.26	60.92	58.09	-0.29%	-2.19	-2.01	-2.22	1.37%	-3.35	-2.59	-3.43	2.39%
				Average:	58.27	60.89	58.08	**-0.33%**	-2.18	-1.96	-2.23	**2.45%**	-3.35	-2.57	-3.42	**1.99%**
51273-6-22	9	5	0.5	15	58.26	61.02	58.05	-0.36%	-2.17	-2.18	-2.21	1.84%	-3.36	-2.58	-3.40	1.19%
51273-6-13	11	5	0.5	15	58.30	61.06	58.15	-0.26%	-2.15	-1.79	-2.20	2.33%	-3.30	-2.62	-3.43	3.94%
51273-6-12	15	5	0.5	15	58.25	60.91	58.09	-0.27%	-2.16	-2.01	-2.20	1.85%	-3.35	-2.56	-3.39	1.19%
				Average:	58.27	61.00	58.10	**-0.30%**	-2.16	-1.99	-2.20	**2.01%**	-3.34	-2.59	-3.41	**2.11%**
51273-7-14	7	5	0.5	45	58.25	60.83	58.07	-0.31%	-2.16	-2.00	-2.20	1.85%	-3.35	-2.57	-3.39	1.19%
51273-7-15	12	5	0.5	45	58.25	60.98	58.05	-0.34%	-2.18	-1.97	-2.21	1.38%	-3.34	-2.58	-3.40	1.80%
51273-6-19	14	5	0.5	45	58.27	60.90	58.08	-0.33%	-2.15	-2.01	-2.20	2.33%	-3.37	-2.55	-3.40	0.89%
				Average:	58.26	60.90	58.07	**-0.33%**	-2.16	-1.99	-2.20	**1.85%**	-3.35	-2.57	-3.40	**1.29%**
51273-6-12	6	5	15	45	58.27	60.97	58.07	-0.34%	-2.16	-2.01	-2.25	4.17%	-3.34	-1.99	-3.43	2.69%
51273-7-5	8	5	15	45	58.29	60.87	58.11	-0.31%	-2.18	-2.01	-2.21	1.38%	-3.38	-2.53	-3.43	1.48%
51273-6-28	10	5	15	45	58.25	60.68	58.10	-0.26%	-2.18	-2.07	-2.21	1.38%	-3.40	-2.53	-3.43	0.88%
				Average:	58.27	60.84	58.09	**-0.30%**	-2.17	-2.03	-2.22	**2.31%**	-3.37	-2.35	-3.43	**1.69%**

L, L=0 yields black and L=100 indicates white

a, negative values indicate green while positive values indicate red and its position between yellow and blue

b, negative values indicate blue and positive values indicate yellow

A collective summary of the results obtained for the panels coated with the VCPI dye solution is provided in Table A-11. As shown, the results indicate that a 30-second dye dwell time will provide the same labeling potential as a 15 minute time. Rinse period has little effect on rinse efficiency as measured by any measurable changes in the color of the painted panel surfaces.

Table A-11. Comparative Analysis of Test Results Collected from Test Panels Coated with Navy-VCPI Dye Solution

Weight Measurements		Average	
		Bare Panels	Contaminated
Dwell Time	**Rinse Time**	**Clean**	
(min)	**(sec)**	**(%)**	
15	15	0.002%	0.006%
7.75	30	0.005%	0.008%
0.5	15	0.002%	0.010%
0.5	45	0.004%	0.006%
15	45	0.003%	0.007%

Datacolor Measurements		**Average Resultant Change from Clean**					
Dwell Time	**Rinse Time**	**L***		**a***		b*	
(min)	**(sec)**	Bare Panels	Contaminated	Bare Panels	Contaminated	Bare Panels	Contaminated
15	15	-0.14%	-0.33%	0.76%	3.53%	0.40%	1.29%
7.75	30	-0.14%	-0.33%	0.00%	2.45%	1.59%	1.99%
0.5	15	-0.12%	-0.30%	0.15%	2.01%	0.79%	2.11%
0.5	45	-0.08%	-0.33%	0.00%	1.85%	0.88%	1.29%
15	45	-0.15%	-0.30%	1.35%	2.31%	1.09%	1.69%

2.2 VCPI Application Unit Design, Modification

Prior to arriving at the test platform location, Battelle will procure a commercially available spray unit for use spray applying the VCPI dye solutions to the surfaces of the A-10 aircraft and ship hull. This sprayer will have a small 1-gallon air pressurized reservoir for storage of the respective VCPI dye solutions, and will be fit with an adjustable spray nozzle so that the flow volume and mist dispersion of the dye solution can be easily adjusted by the operator. It is important that the nozzle be fully adjustable so that the spray pattern and distributed droplet size can be adjusted. The preferred VCPI application system for the proposed demonstrations may involve a High Volume Low Pressure (HVLP) hand-held spray gun that is often used by DoD personnel for applying paint to aircraft and ship structures. As required, this Commercial-Off-The-Shelf (COTS) spray gun will be modified to accomplish the goals of the respective Dem/Val tests.

As described previously a series of laboratory-scale testing was conducted using a airless spray gun; however, a series of laboratory and/or pre-Dem/Val tests are required with the HVLP spray unit and each of the VCPI dye formulations intended for use at both HAFB and MNS. These tests will be used to determine the optimum settings for the following conditions for full Dem/Val field testing:

- VCPI concentrate formula
- Application unit droplet size and spray pattern
- Water/VCPI flowrate.

Once these conditions are obtained, the project team will conduct a small spray demonstration in the lab to confirm these settings. Please note that once on-location, these starting points may need to be altered due to unknown distances to surfaces and weather conditions.

2.3 Initial VCPI Dye Solution Spray Test

In order to confirm that the VCPI dye technology and the spray gun equipment are compatible, efficient in delivering the dye solution to the contamination source, and to make any last minute adjustments to the equipment, the spray unit and VCPI dye formulations intended for use at each location will be pre-tested at Battelle prior to any on-site demonstration. As required, a pre-demonstration of the VCPI technology will also be conducted on-site prior to conducting the actual Dem/Val test on DoD assets. This type of pre-Dem/Val test is being required by the A-10 Systems Program Office, as a way of validating the technology before allowing the formal Dem/Val to be conducted on an actual A-10 aircraft. No such pre-demonstration test is being required by the Navy.

For any Air Force spray pre-demonstrations tests, the HVLP spray unit will be assembled and tested with filtered tap water. Once the operation of the unit using water is satisfactory, the team will gather a minimum of three (3) medium size aluminum panels that are bare or uncoated and at least a single panel that is coated with a T.O. 1-1-8 approved military-specification coating (MIL-PRF-85285). These panels will be contaminated with several different hydrophobic materials (lubricating oil, grease, and hydraulic fluid), allowed to air dry for 24 hours, and then evaluated with the Air Force VCPI dye solution. Testing on these panels will include application efficiency, labeling effectiveness, visual detection by operators, and removal with both mechanical agitation and cold water rinsing operations. All efforts will be to confirm adequate labeling and detection within the optimized dwell times determined during the laboratory tests. In addition, an effort will be made to demonstrate any differences between manual (pole) and pneumatic scrubbing processes. Testing will also confirm that there is no adverse staining of coated test panels or the platforms/flooring beneath the panels.

A second set of three (3) FEHY-80 steel test panels coated with a protective acrylic grey colored paint will be contaminated with a salt-water/biofilm contamination. This contamination will come from actual sea water that was collected from the Atlantic Ocean near Ponce de Inlet, FL. The contaminant will be allowed to thoroughly air dry prior to conducting any VCPI tests. As with the Air Force VCPI pre-demonstration, the Navy VCPI dye solution will be spray applied to the test surfaces of each panel using the set-points determined during the application unit design and construction. After application, panels will be briefly rinsed and observed. If the contamination is not visually indicated in an acceptable manner (not too light, not too dark from a distance of 15 meters), the variables that can be adjusted will be adjusted on a one-by-one basis and then re-sprayed on cleaned and re-contaminated panels. This process will be repeated until acceptable results are obtained for each formulation and contamination combination. This optimization in the field is not anticipated based on the observations collected during the laboratory tests.

3.0 Hill AFB Demonstration

3.1 Pre-demonstration and Technology Approval

Prior to beginning any demonstration activities at Hill AFB, all applicable pre-approvals will need to be obtained from several departments at Hill AFB. First, approvals from the environmental department must be obtained to insure that the team will be operating within the Hill AFB regulatory confinements. Permission to proceed from authorities from the A-10/Hill AFB management must be obtained in writing, and will be contingent upon the results obtained during the pre-Dem/Val tests that will be conducted on several A-frame test panels that are designed to replicate the airframe surfaces of aircraft processed at Hill AFB. This simple test should take no longer than a day's time and can either be done during a separate visit to Hill AFB, or at the start of the demonstration if that is acceptable to Hill AFB/A-10 authorities. Either way, this pre-demonstration test must be completed before the formal Dem/Val on the A-10 is approved and scheduled. Approval letters will be submitted to Battelle authorizing them to proceed with the demonstration.

3.2 Demonstration Schedule

Once the proper approvals have been obtained, the team can proceed with the full process demonstration on the lower wing and fuselage surfaces of an A-10 aircraft. It is planned that the demonstration schedule will go as is listed in Table A-12..

Table A-12. Hill AFB Schedule of Events

Day	Activity
Day 0	Arrive on location
Day 1	Kick-off meeting and set-up
Day 2	Pre-demo contained test
Day 3	Full-scale demonstration
Day 4	Full-scale demonstration
Day 5	Equipment tear-down and wrap-up meeting
Day 6	Reserved for make-up day if weather delays occur

Time is reserved at the close of the demonstration for any delays that may be incurred during the demonstration. The demonstration week will be scheduled at the convenience of the Hill AFB personnel and their operations.

3.3 Test Unit & Contamination Description

The team intends to inspect and document any areas on a single A-10 aircraft (ref. Figure A7) that contains visual evidence of hydrophobic contamination prior to conducting any normal cleaning operations on the aircraft. This aircraft is specially designed for close air support of ground forces.

Figure A7. Photograph of an A-10 Aircraft

Normal maintenance operations conducted on the stripped surfaces of this aircraft include a thorough water rinse and alkaline soap wash. All surfaces of the aircraft are cleaned using Scotchbrite pads that mechanically agitate any contamination, which then is removed from the surfaces of the airframe during the pressurized water rinsing operation. Once rinsed, the aircraft is allowed to air dry while other areas (nose and main landing gears) on the aircraft are cleaned. Post-cleaning maintenance operations completed on the aircraft include any masking of structures, followed by a 3-step application of the PreKote® non-chromate pretreatment. The photographs shown in Figures A8 through A11 serve to document the types of contamination found on the lower surfaces of the aircraft, as well as the cleaning operation and PreKote application.

Figure A8. Hydrophobic Contaminants on Lower Surfaces of A-10 Wings

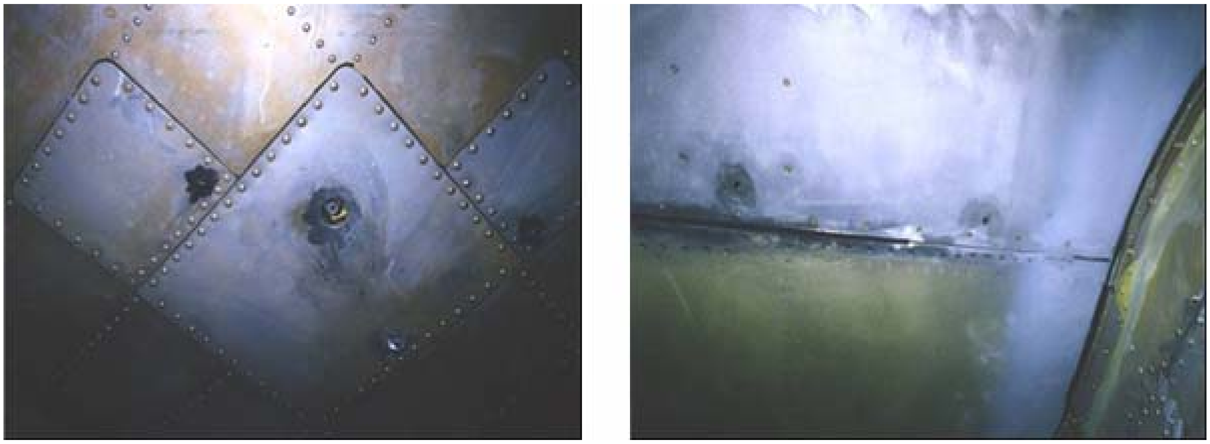


Figure A9. Typical Hydrophobic Contamination on Underside Surfaces of A-10 Wings

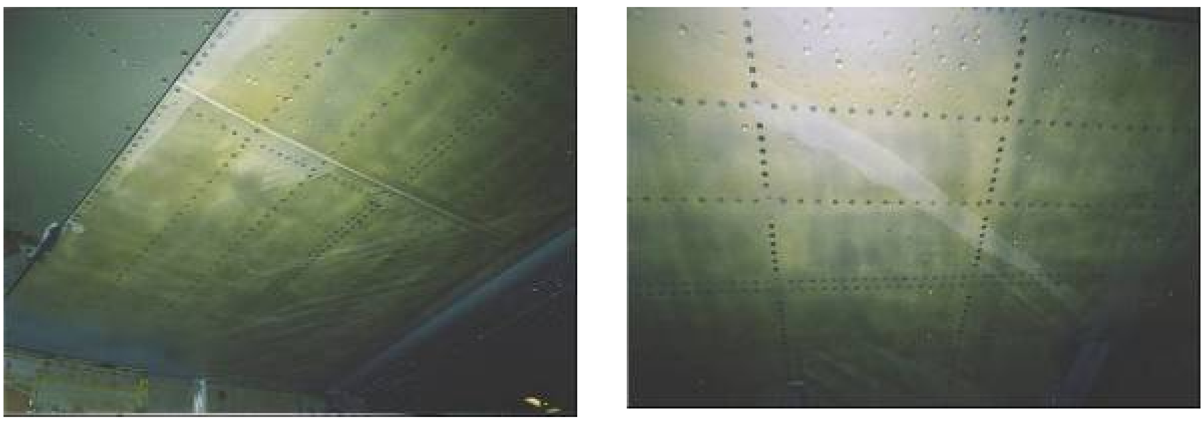


Figure A10. Underwing Surfaces of A-10 Wing After Alkaline Soap Wash and Water Rinse

Figure A11. Application of PreKote Surface Pretreatment

Discussions with Air Force personnel confirm that the VCPI technology would be evaluated during this Dem/Val test as a quality control check of the cleaning operations and PreKote application process. Specifically, the VCPI dye solution would be applied to the underside surfaces of the wings and fuselage where there are traditional coating adhesion problems as a result of poor cleaning practices or a continuous leakage of hydraulic fluids, oils, and fuel prior to applying the primer and topcoat scheme to the aircraft structures. The VCPI technology would be used to visually identify improperly cleaned surfaces, residual contamination, and cleaning efficiency as a function of variability between production operators on different shifts and mechanical agitation methods (i.e., manual versus pneumatic).

3.4 Demonstration Set-up

Once the team arrives on-site, materials that have been shipped in advance will be located. In addition to normal testing supplies, the team will be shipping the spray applicator and the concentrated VCPI dye solution. The spray applicator will be assembled and tested to confirm its operability. The unit will be moved to the best staging area for the subsequent demonstration.

In addition to setting up the unit, the team plans to hold a pre-Dem/Val meeting with the production staff, A-10 management and engineers, and other personnel to address any last minute concerns. It is anticipated that Mr. Richard Buchi (Hill AFB) will facilitate the invitation of the correct parties to that meeting. A short safety briefing will be incorporated into this meeting, as well as a technology overview. Participants in the demonstration will be expected to attend this meeting.

3.5 Details of Dem/Val Testing

Table A-13. Proposed Demonstration Testing Methods listed in Table A-13 document the types of testing that are anticipated in conjunction with this demonstration. It is expected that a Standardized Test (Test 1) will be initiated first, followed by the testing described Tests 1 and 2, in no particular order. The team intends to use the technology multiple times and will alternate between these types of testing throughout the duration of the demonstration.

Table A-13. Proposed Demonstration Testing Methods

Test	Demonstration Activity	Description of Testing	Expected Outcome
1	Standardized Testing via Artificial Contamination	In order to establish a base case for the technology, a section on the underside surfaces of the aircraft will be cleaned until a passing water break test has occurred. Following this, the area will be subdivided into a 'clean' side and a 'dirty' side. On the 'dirty' side, contamination in the form of a MIL-SPEC hydraulic fluid and grease that is used in conjunction with the A-10 aircraft will be wiped on, and then wiped so that the surface is smooth (does not contain lumps of grease). VCPI will then be spray applied to both areas. Following the rinsing of the excess VCPI solution from the aircraft, the area will be observed for visual indication of the contamination. Once all observations are made, the aircraft surface will be thoroughly cleaned.	It is expected that VCPI will label the area that has been artificially contaminated with oil or grease but will not leave an indication of contamination on the 'clean' side. It is also anticipated that the marked contamination will be easily removed following normal cleaning protocols.
2	Normal Operation	Normal procedures would dictate that the aircraft would be cleaned prior to any surface	It is anticipated that the cleaning operation will be good,

Test	Demonstration Activity	Description of Testing	Expected Outcome
	Verification	treatments required. In this test, an aircraft in line for normal maintenance will be cleaned as normal. VCPI will be applied a certain cleaned area of the aircraft and subsequently rinsed from the surface. The color remaining will mark areas where the cleaning efforts were inadequate and surface treatments may not be as effective. The remaining contaminated areas will be cleaned. Then followed with the appropriate surface treatments.	but not perfect. It is expected that VCPI will mark small patches of residual surface contamination, or larger areas that may have been overlooked during the cleaning operations.
3	Pre-treatment Application Option	Prior to cleaning, VCPI can be used to mark the surface contamination, allowing for a more efficient cleaning. A normal aircraft prior to cleaning operations would have part of its lower wing and fuselage surfaces treated with VCPI. This would subsequently be rinsed. The remaining color on the surface would indicate where cleaning personnel are required to focus efforts. Once the marker has been removed from the surface, the surface should be clean and ready for further surface treatments.	It is expected that VCPI will label a large portion of the treated area because the aircraft has not been cleaned. This allows the operator a chance to efficiently clean the aircraft and have a good visual indication when the cleaning operation has succeeded and the aircraft can proceed for further maintenance.
4	This test will be designed to assess any differences in cleaning efficiency for the manual pole scrub and pneumatic power scrub.	The VCPI dye solution would be spray applied to sections on the RH and LH sides of the lower wing surfaces. The solution would be allowed to dwell for 30 seconds, rinsed with water, inspected, sprayed with PreKote, and then scrubbed with the respective scrubbing processes. Post-scrubbing operations will include a water rinse, inspection, and re-application of the VCPI dye solution.	This test is intended to document any differences between the pole and power scrubbing operations that are normally completed during the first application of the PreKote pretreatment. As designed, the results of the test should be useful in verifying how clean is clean prior to proceeding with the second stage water rinse and PreKote application.

The demonstration will be considered a success if:

- The technology labels contamination, and this contamination can then be easily removed during cleaning operations,
- The technology indicates during normal cleaning operations areas that were overlooked or not focused on,
- The technology allows for more efficient cleaning by giving maintenance personnel visual indications of where cleaning efforts need to be focused,
- The technology can be implemented without affecting other process steps in a negative manner (either by time, cost, or process interruption),
- The technology is cost efficient, i.e., the cost of the technology is covered in the cost of time it saves during cleaning operations by allowing the operators to directly focus efforts on contaminated areas of the aircraft.

Additionally, it needs to be noted if the application and process of using VCPI area success per the first 4 criteria listed above, it is anticipated that the subsequent surface treatments will be applied to a cleaner surface which should, in turn, extend their lifetime and may extend the maintenance cycle for these processes.

3.6 Technology Demobilization

At the close of the demonstration, the equipment will be drained of all fluid, rinsed, and allowed to air dry. All equipment will then be securely packed and shipped back to Battelle at the following address:

> Battelle
> Attn: Kevin Rose (phone: 614-424-7111/cell: 614-378-1740)
> 505 King Ave.
> Columbus, OH 43201

The remaining additional supplies will be either disposed of or shipped back to Columbus with the unit.

3.7 Post-Demonstration Analysis

To close this demonstration activity, Battelle will hold a closing meeting with the observers from Hill AFB. Observations from personnel involved with the demonstration will be solicited. (Please refer to Appendix B for a sample questionnaire that will be provided to Hill AFB representatives to help facilitate an evaluation of the technology.)

4.0 Mayport Naval Station Demonstration

4.1 Pre-approval Period

Prior to beginning demonstration activities at the Mayport Naval Station, pre-approvals will need to be obtained from several departments at Mayport. First, approvals from the environmental department must be obtained to insure that the team will be operating within Mayport's regulatory confinements. Permission to proceed from the Captain of the vessel must also be obtained. It is anticipated that Dr. Scott Sirchio (NSWCCD) will obtain this permission from Mr. Robert Tierney in the weeks prior to the demonstration. It is unlikely that Mayport will require a pre-demonstration spray test on coated panels with the VCPI spray fully contained prior to the demonstration in order to confirm that the release of VCPI in the port will not have any visual effects of concern. This simple spray test was conducted in a large body of fresh water, and no dispersion or dye coloration issues in water are anticipated based on conversations with Navy representatives. Approval letters will be submitted to Battelle authorizing them to proceed with the demonstration.

4.2 Demonstration Schedule

Once proper approvals have been obtained, the team can proceed with the demonstration. It is planned that the demonstration schedule will go as is listed in Table A-12.A-14. Due to ship scheduling of its activities in Port, it is likely that it will not be possible to obtain permission from the Captain to proceed until right before the demonstration.

Table A-14. Mayport Naval Station Schedule of Events

Day	Activity
Day 0	Arrive on location
Day 1	Kick-off meeting and set-up
Day 2	Pre-demo contained test
Day 3	Full-scale demonstration
Day 4	Full-scale demonstration
Day 5	Equipment tear-down and wrap-up meeting
Day 6	Reserved for make-up day if weather delays occur

Time is reserved at the close of the demonstration for any delays that may be incurred during the demonstration. The demonstration week will be scheduled at the convenience of the Mayport Naval Station personnel and their operations.

4.3 Test Unit & Contamination Description

It is planned that the demonstration will occur on the front hull of a Guided Missile Frigate (ref Figure A12) or other similar vessel that has harbored at the Mayport Naval Station for its routine maintenance cycle.

Figure A12. Photograph of Guided Missile Frigate

Once a vessel has pulled into port, the ship's personnel begin routine maintenance. The sides of the ship are rinsed (in some cases observed, a good, steady rain, suffices for their operations) for their 'pre-clean' operations.

Cleaning operations here are intended to remove any oil and grease, biofilm, and salt contamination (ref. Figure A13). Salt contamination is the primary concern at this facility. The Navy is concerned with the cleanliness of the surface prior to painting operations for several reasons. First, trapped salt contamination can lead to surface corrosion (ref. Figure A14) and second, rusting and surface contamination can lead to a reduced paint lifetime. Repainting ships more frequently than necessary contributes to increased costs of personnel time and unnecessary consumption of the hazardous chemicals used for painting.

Figure A13. Salt and Biofilm Contamination on Lower Ship Hull

Figure A14. Rust on Lower Ship Hull

Once rinsed, the ship is allowed to dry and the surfaces above water are then painted (ref. Figure A15).

Figure A15. Sailor Painting Side of Ship Hull at Mayport

Painting operations are complete during dockside maintenance when the entire vessel is painted. Paint stripping does not occur dockside, but does occur during scheduled maintenance at a dry-dock facility.

4.4 Demonstration Set-up

Once the team arrives on-site, materials that have been shipped in advance will be located and unpacked. In addition to normal testing supplies, the team will be shipping the spray applicator and approximately 5 gallons of the VCPI dye solution. The spray applicator and extension lines will be assembled and tested with tap water to confirm its operability. The unit will then be transferred to the best pierside staging area in preparation of the demonstration.

In addition to setting up the demonstration equipment, the team plans to hold a kick-off meeting with the involved parties to address any last minute concerns. It is anticipated that Dr. Scott Sirchio and Mr. Bob Tierney (NAVSEA and MNS, respectively) will facilitate the invitation of the correct parties to that meeting. A short safety briefing will be incorporated into this meeting, as well as a technology overview and schedule of activities. Participants in the demonstration will be expected to attend this meeting.

4.5 Details of Demonstration Testing

If required by Mr. Tierney, Battelle will spray a small quantity (~ ½ gallon) of the VCPI dye solution to a non-test section of a ship hull that is docked pierside. This material will be allowed to dwell for ~ 1 minute, and then thoroughly water rinsed into the sea water below. The purpose of this mini pre-Dem/Val test will be to confirm the dye dispersion results obtained by Battelle in a large fresh water lake.

Table A-15 lists the types of testing that are anticipated in conjunction with this demonstration. It is expected that a Standardized Test (Test 1) will be initiated first, followed by the testing described Tests 2 and 3, in no particular order. The team intends to use the technology multiple times and will alternate between these types of testing throughout the duration of the demonstration.

Table A-15. Proposed Demonstration Testing Methods

Test	Demonstration Activity	Description of Testing	Expected Outcome
1	Standardized Testing	In order to establish a base case for the technology, a 10' by 10' section of the painted ship hull will be rinsed with potable water, and considered the 'clean' or control area. Adjacent areas will not be rinsed and will be considered the 'dirty' or contaminated areas. On the 'dirty' side, contamination in the form of salt spray that is observed on normal vessels from operational duty will be allowed to air dry. VCPI will then be spray applied to both areas, allowed to dwell for 30 seconds, and then rinsed with a low-pressure water. Following the rinsing of the excess VCPI solution from the surface, the area will be observed for visual indication of the contamination. Once all observations are made, the surface will be cleaned.	It is expected that VCPI will label the area that is contaminated with the dried salt residues but will not leave an indication of contamination on the 'clean' side. It is also anticipated that the marked contamination will be easily removed during the water rinse operations and after normal cleaning protocols.
2	Normal Operation Verification	Normal procedures would dictate that the painted hull surfaces of a vessel are water rinsed prior to any surface treatments required. In this test, a vessel in line for routine maintenance will be rinsed per protocol. VCPI will be applied to a cleaned area of ~100 ft^2 and then subsequently rinsed from the surface. The color remaining will label areas where the cleaning efforts were inadequate and surface treatments may not be as effective. The remaining contaminated areas will be cleaned, and then followed with the appropriate surface treatments.	It is anticipated that the cleaning operation will be good, but not totally adequate. It is expected that VCPI will selectively label small patches of surface contamination, or larger areas that may have been overlooked during the cleaning operations.
3	Pre-treatment Application Option	Prior to cleaning, VCPI can be used to mark the surface contamination, allowing for a more efficient cleaning. A 10' by 10' hull section of a normal vessel prior to cleaning operations would have part of its surface treated with VCPI. This would subsequently be rinsed. The remaining color on the surface would indicate where cleaning personnel are required to focus efforts. Once the marker has been removed from the surface, the surface should be clean and ready for further surface treatments.	It is expected that VCPI will mark a large portion of the treated area because the vessel has not been cleaned. This allows the operator a chance at efficiently cleaning the ship and having a good visual indication when the cleaning operation has succeeded and the vessel can proceed for further maintenance.

The demonstration will be considered a success if:

- The technology efficiently labels the dried salt and grease contamination, and this contamination can then be easily removed during cleaning operations,
- The technology indicates during normal cleaning operations areas that were overlooked or not focused on,
- The technology allows for more efficient cleaning by giving maintenance personnel visual indications of where cleaning efforts need to be focused,
- The technology can be implemented without affecting other process steps in a negative manner (either by time, cost, or process interruption),
- The technology is cost efficient, i.e., the cost of the technology is covered in the cost of time it saves during cleaning operations by allowing the operators to directly focus efforts on contaminated areas of the aircraft.

Additionally, it needs to be documented if the spray application and process of using VCPI area success per the first 4 criteria listed above, it is anticipated that the subsequent surface treatments will be applied to a cleaner surface which should, in turn, extend their lifetime and may extend the maintenance cycle for these processes.

4.6 Technology Demobilization

At the close of the demonstration, the equipment will be drained from fluid and rinsed. It will be securely packed and shipped back to Battelle at the following address:

Battelle
Attn: Kevin Rose (phone: 614-424-7111/cell: 614-378-1740)
505 King Ave.
Columbus, OH 43201

The remaining additional supplies will be either disposed of or shipped back to Columbus with the unit.

4.7 Post-Demonstration Analysis

To close the demonstration, Battelle will hold a closing meeting with the observers from the Mayport Naval Station. Observations from personnel involved with the demonstration will be solicited.

5.0 Reporting

Following the tests, the Battelle team will compile their report and distribute a draft to the entire team, which should be reviewed by 30June 2006 with the intention of issuing a final test report during mid-August 2006

A full Cost and Performance Report will be prepared by Battelle upon receipt of team comments and completion of a detailed cost assessment.

The report will form the basis for reporting to the ESTCP sponsor.

Appendix B
Analytical Methods Supporting the Experimental Design

The following methods were used to validate the efficiency and effectiveness of VCPI labeling and removal on all laboratory test panels. Panels sets included 2024-T3 aluminum alloy sheet (Air Force platform), and primer coated HY80 steel alloy (Navy platform).

1. **Weight Change** - Each panel before use was weighed on an analytical balance in grams to 4 decimal places in a constant temperature humidity laboratory. This data was used to track the degree of contamination and labeling throughout this test and to identify the effectiveness of the rinse process in removing both VCPI labels.

2. **Light Box Visual Comparison –** Test panels were analyzed for visual comparison purposes under the lighting of conditions of Daylight, Incandescent and Cool White Fluorescence. This testing required a special Light Box with multiple light sources installed in the observation box, with only an open front. In order to perform this analysis all outside sources of light were turned off and included the closing of window blinds to the laboratory. Visual observations under the various lighting conditions are of using AMA's light box under all (3) lighting conditions, with photographs to be taken of the test panels (including a blank). A rating system was employed with 5 being clean and 1 being very observable. Comparisons of post labeling were performed and test blanks were inserted into the group photograph as a visual reference. Panels were observed only after having been static air dried.

3. **Data Color (color space coordinates)** - See Report SERDP **–** P1117 for analytical protocols and data reduction. Here each panel was measured individually and the L*a*b* values reported for color variation between the clean un-contaminated panel and the post Contaminated/Labeled/Rinsed values. This data provided us with a mathematical means to compare the results.

4. **Water Rinse Apparatus –** As shown in Figure B1, an apparatus was constructed to rinse up six panels simultaneously with equal volumetric flows from individual flat plane nozzles. The panels were suspended in the vertical plane facing forward in the apparatus for ease of VPIC® Label application in a laboratory hood. At the end of the prescribed labeling contact dwell time, a toggle switch was thrown which opened a pressure regulated solenoid valve controlling the flow volumes from the nozzles across the panel surfaces. Immediately upon completion of the prescribed rinse time, the same toggle switch controlling the solenoid valves was placed into the off position ceasing all water rinsing.

5. **Water Break** - Test used on B&B Re-Gel cleaned <u>bare</u> panels only.

6. **UV/Visible Spectroscopy**. See analytical protocol summaries in SERDP Final Report.

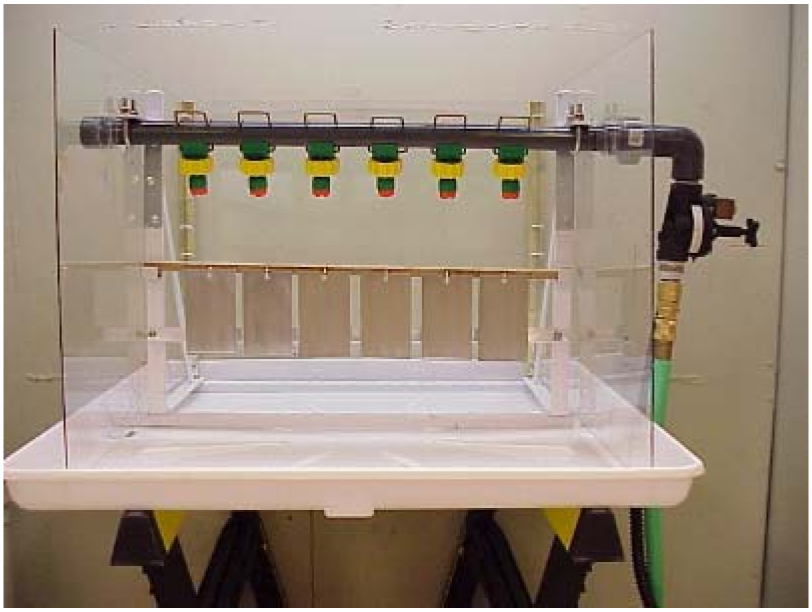


Figure B1. Laboratory VCPI Spray and Water Rinse Set-up

Appendix C
Additional Product Testing for Non-JTP Applications

Air Force Application VCPI Formulation and Use Protocol Selection [Preliminary (Lab-scale) Validation]

Materials: For the AF A-10 under wing case, Al-2024-T3 panels supplied by Q-Panel, Inc. were used as the basis metal and test coupons. Each 3"x10" panel was cut to 3"x 5" and a center top hole punched the equivalent size of the factory supplied opening. Each panel was treated according to a set of experimental run sheets for the specific field process to be examined.

Test Objectives and Strategy: The test objectives are provided in the header of each flow scheme starting with Scheme 1. The test strategies are laid out in the following flow schemes starting with Scheme 1, and in the Run Sheets, which are included in the following text.

Test Procedures and Methods:
The panels were cleaned by degreasing with light abrasive action according to the protocol of Scheme 1 and to produce bare aluminum surfaces with only a fresh, thin and adherent oxide film surface. For panels that will be used in additional testing, a preliminary cleaning step of tap water rinsing, followed by applying 25% ReGel and scrubbing until lather with 240 grit sanding disk. This cleaning step was then followed by a thorough DI-water rinse. Each panel must pass water-break testing (WBT). If not, the panel was either re-cleaned such that it does pass the WBT, or it was discarded. To produce a contaminated panel, the middle two inches of each panel were coated lightly with a MIL-SPEC approved hydraulic fluid (MIL-PRF-83282 or MIL-H-5606) using a Kim-Wipe towel dampened with the fluid. The panels were suspended in the vertical plane from the rinse apparatus panel holders. The panel surfaces were then wetted with the tap water from the rinse apparatus, before they were sprayed with a specific VCPI solution in a vented hood as per the run or log sheet prepared for each test, i.e. listing specific time for operations, sprayer settings, VCPI formulation, VCPI labeling dwell time, along with the observations to be made, and post panel treatment analyses to be run.

For the case of detecting hydraulic fluid under wing, the approach was to administer the VCPI label using a production-quality paint spray gun. Such a device permits a good control of the spray pattern and loses very little of the VCPI solution to overspray or dripping. Unlike paint, the VCPI solution is not prone to cause rapid nozzle plugging as it is a solution and not a suspension of pigment particles, as is paint. Hence, frequent and extensive cleaning of the nozzle was not needed and simple water rinsing (in the case of the Navy application) or XG flush, followed by a water rinse (in the case of the AF application). This maintenance expectation was verified during the laboratory phase of testing.

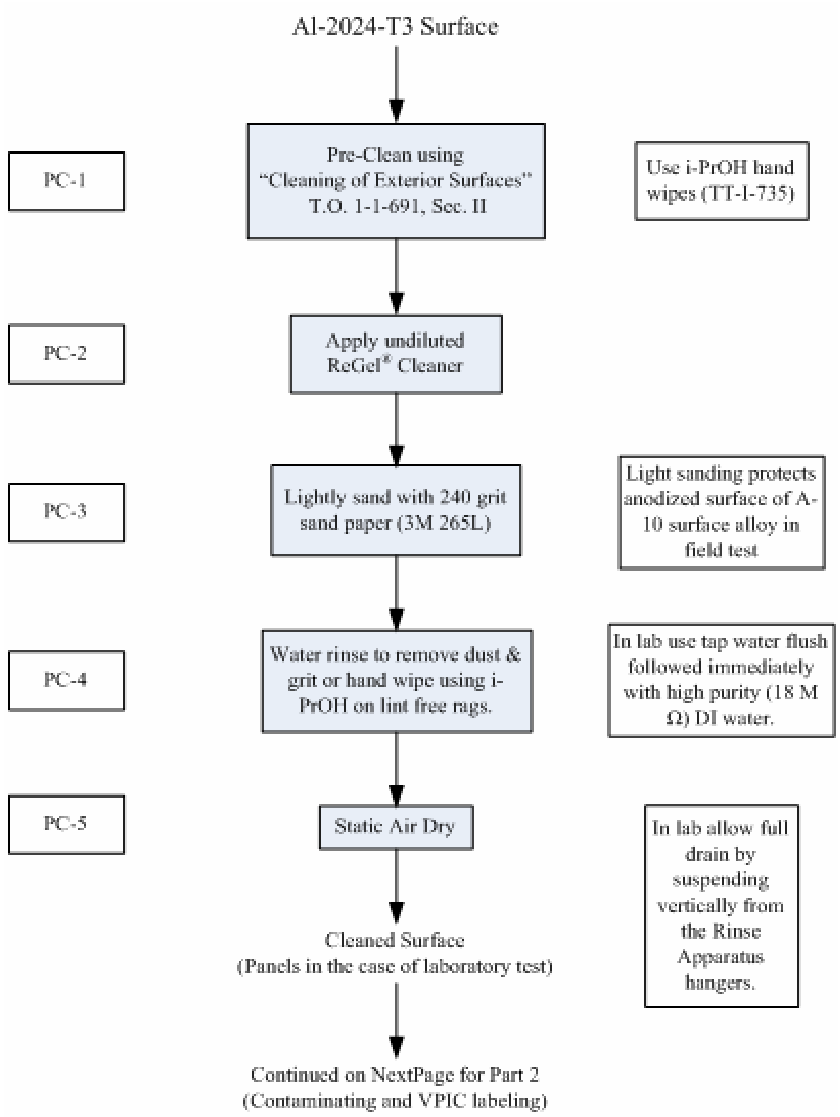
To prepare the VCPI labeling solution, ORO dye were dissolved in i-PrOH and then added to carrier/diluent liquid. [Aqueous XG was the primary carrier selected, others could be evaluated if needed] to produce a liquid that is a simple solution or stabilized dispersion. The XG solution was most preferred if sufficient ORO can be dispersed in it. If an emulsion is required, then ORO can be dissolved in a MIL-SPEC cleaner that is already in use at Hill AFB ALC, e.g. Re-Gel could be considered. As ORO, like hydrophobic contaminants such as hydraulic fluid, grease and lube oils, are insoluble in water, and so a simple aqueous solution cannot be prepared. A comparison evaluation of the effect if any of the VCPI labeling of bare control panels prepared in accordance with testing protocols was performed. In this work the utilization of the same statistical test plan was performed, but using only bare panels.

Panel Test Protocols: The specific lab test protocol is given in Scheme 1.

Scheme 1:

PREKOTE-BASED PROCESS INCORPORATING VCPI MONITORING OF CLEANING STEP FOR EXTERIOR A-10 SURFACES PRIOR TO APPLICATION OF CHROMATED PRIMER AND TOP COAT (Part 1. Pre-Cleaning)

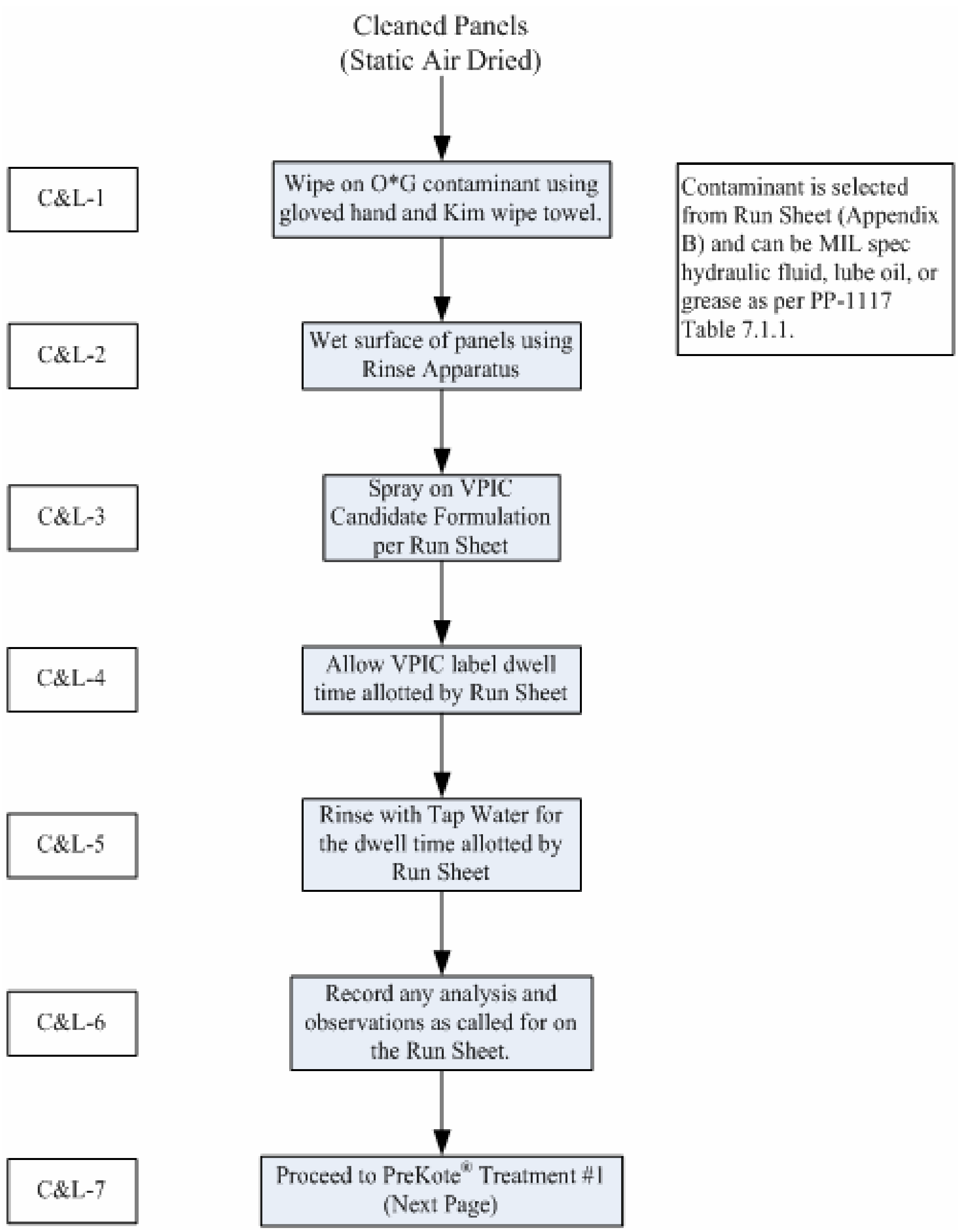
Step # | Process Step Description | Notes



Scheme 1 (Continued):

PREKOTE-BASED PROCESS INCORPORATING VCPI MONITORING OF CLEANING STEP FOR A-10 EXTERIOR SURFACES PRIOR TO APPLICATION OF CHROMATED PRIMER AND TOP COAT (Part 2. Contaminating and VCPI Labeling)

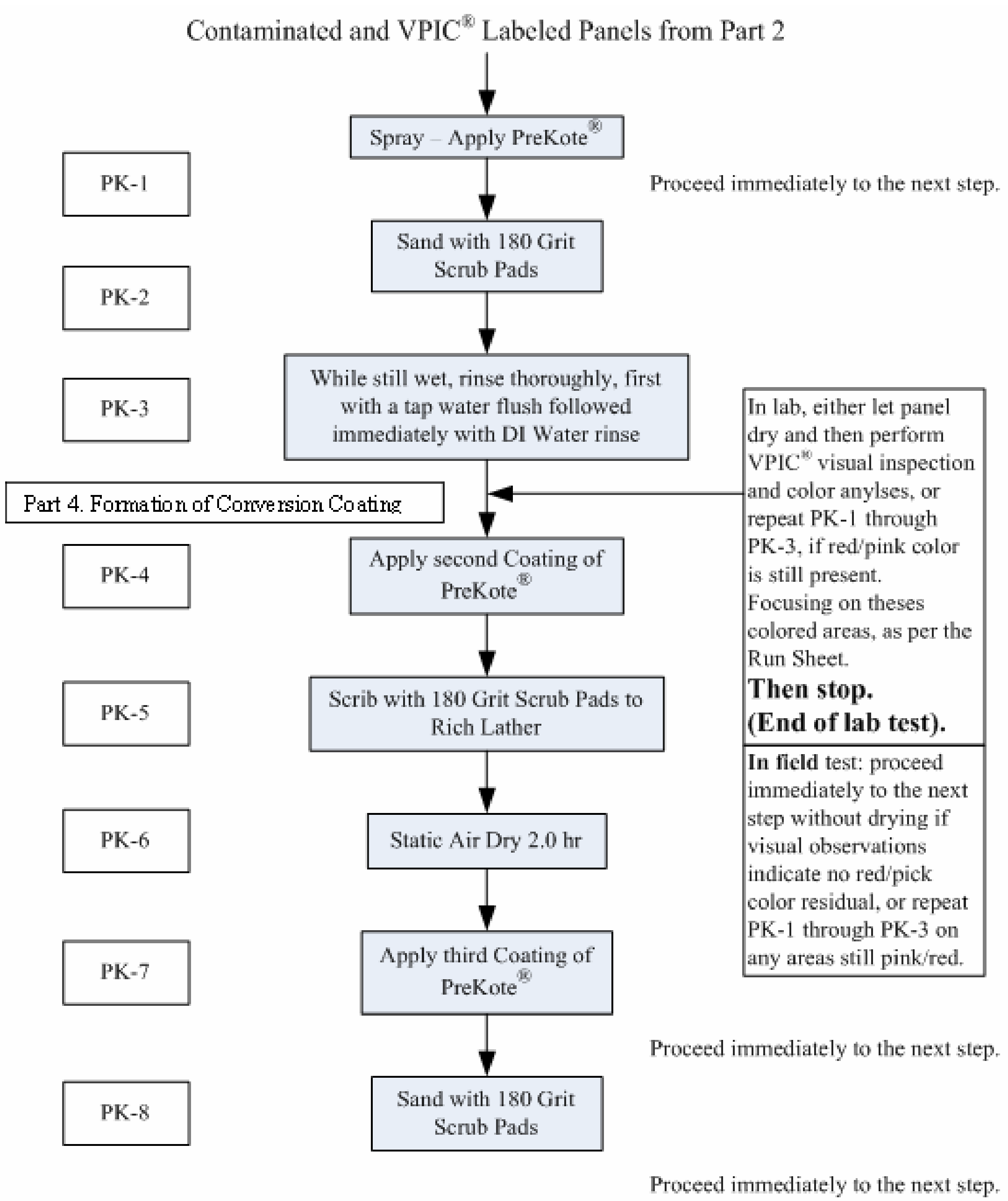
Step # Process Step Description Notes



Scheme 1 (Continued):

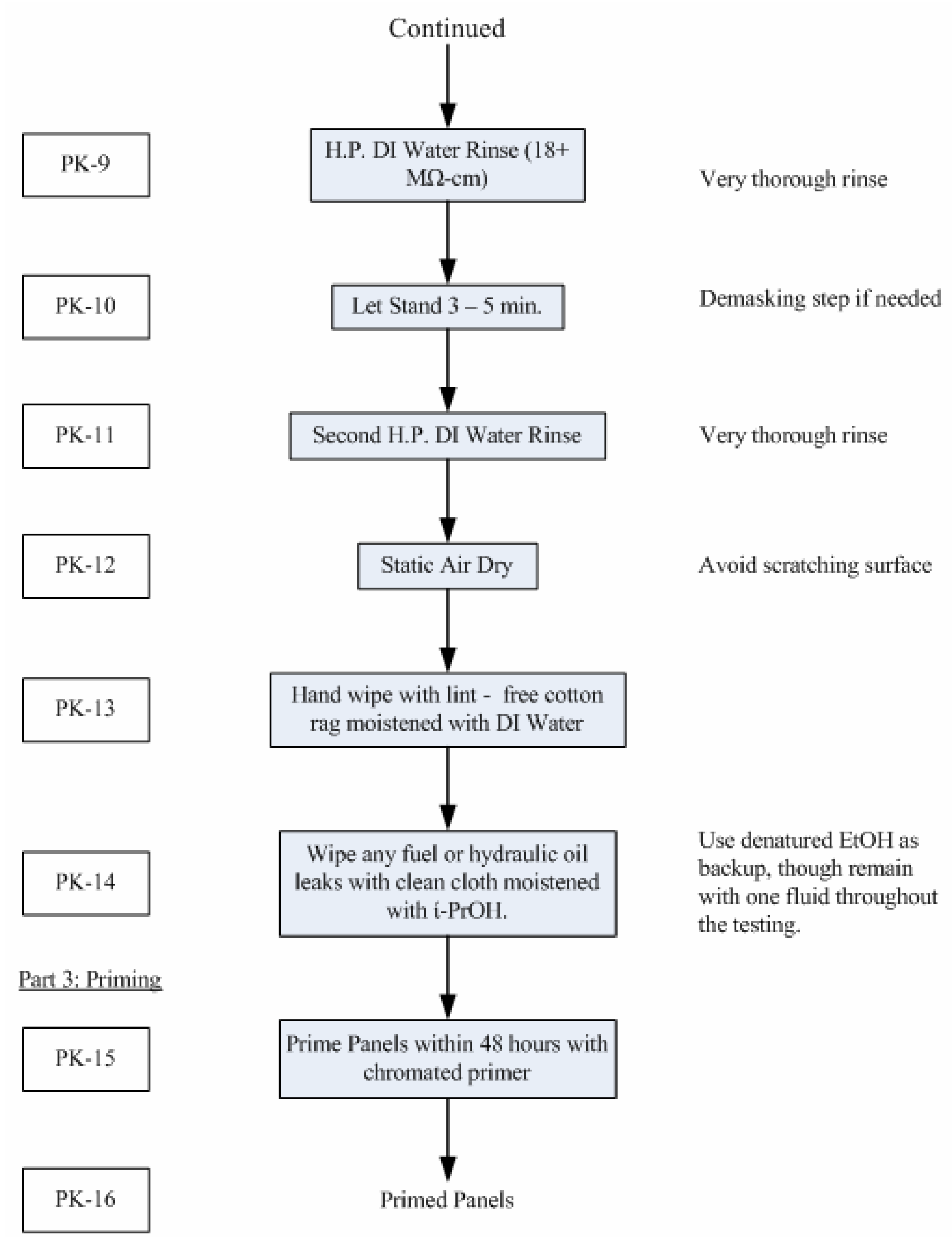
PREKOTE-BASED PROCESS INCORPORATING VCPI MONITORING OF CLEANING STEP FOR A-10 EXTERIOR SURFACES PRIOR TO APPLICATION OF CHROMATED PRIMER AND TOP COAT (Part 3. Cleaning with PreKote with VCPI Monitoring)

Step # Process Step Description Notes



Scheme 1 (Continued):
PREKOTE PROCESS INCORPORATING VCPI FOR EXTERIOR AIRCRAFT SURFACES PRIOR TO APPLICATION OF PRIMER AND PAINT (Part 4 Application of PreKote Conversion Coating -Continued)

Step # | Process Step Description | Notes



Navy Application VCPI Formulation and Use Protocol Selection [Preliminary (Lab-scale) Validation]

The VCPI label sprayer and its operation were discussed previously. The same XG-water base VCPI formulation used for the AF application was used for the Navy application except the VCPI label in this case consisted of a particular food coloring dye (from SERDP PP-1117) selected to track with dissolved corrosive salts.

Fifty Q-Panels of FEHY80 were painted per MIL-DHBK-1110 and oven age cured for this testing following MIL-SPEC protocols, as outlined by MIL-HDBK-1110. Table C-1 documents the panel matrix and sample preparation procedures.

Table C-1. VCPI Process Chemistry, Formulation, and Application Testing Selection – Navy Application

Category	Description	
Materials	Navy MIL spec FEHY80 steel panels	Q-Panel stock #: R-35, Steel Matte Finish. 0.032"T x 3"W x 5"L, Lot # 080999729 Fe. Steel Spec. QQ-S-698, Temper ¼ Hard.
	Sea water (from the Atlantic Ocean, Daytona Beach, FL, USA)	Acquired from Battelle – Daytona Beach Office on 11/15/05 from the Pone Inlet, Florida. Water was refrigerated until use. Water pH of 8.1, with a salinity of 33ppt.
	Navy MIL spec Primer from MIL-HDBK-1110	One coat of TT-P-645, N42Y00100, Zinc Molybate 25, 2 mils dft, supplied by Far West Paint Manuf.
	Navy MIL spec Paint from MIL-HDBK-1110	Two coats of MIL-E-24635, N40A100, Silicone Alkyd Copolymer , supplied by Far West Paint Manuf.
Test Protocol:	**Step #**	**Step Description**
	1	Wash all panel test surfaces with tap water (see PI if heavily soiled or if the panels appearance varies)
	2	Dry sea water on panels by wetting horizontal surface and let dry @ 80°F, then re-wet. Note that, at least for the first couple of coatings that the sea water may bead up in irregular patterns). Repeat 10x or until heavily encrusted with salt. (TAKE PHOTOS). Include each of ; • Sea water-dried panels (for VCPI labeling) • Blank panels (no sea water applied, to remain blank and to be VCPI labeled) • Reference panels (contaminated with dried sea water but without VCPI labeling)

	3	As per the Run Sheet, for each dwell time determination, spray wet (don't flush) surface of vertical panels with each VCPI test formulation without dried sea water and 3 cleaned and painted). Three panels with dried sea water are left unlabeled.
	4	Out of direct sunlight, water rinse each panel set using a garden hose and matching hand sprayer from a fair distance away, 10 to 15 feet as follows. Wash all the panels at the same distance. Carefully monitor the rinsing so that each panel is rinsed in the same manner and time. After each 30 seconds of rinsing, stop and record visual observations as to presence/absence of VCPI dye color. Before rinsing, and after each 30 second rinse, pull a set of panels (3 each of reference and sample). At the end of rinsing (3.0 minutes) include 3 panels for blanks. Note whether any residual VCPI color exists on any of the panels
	5	Record light box visual observations on all panels. Submit the samples for Data Color measurement of color space coordinates.

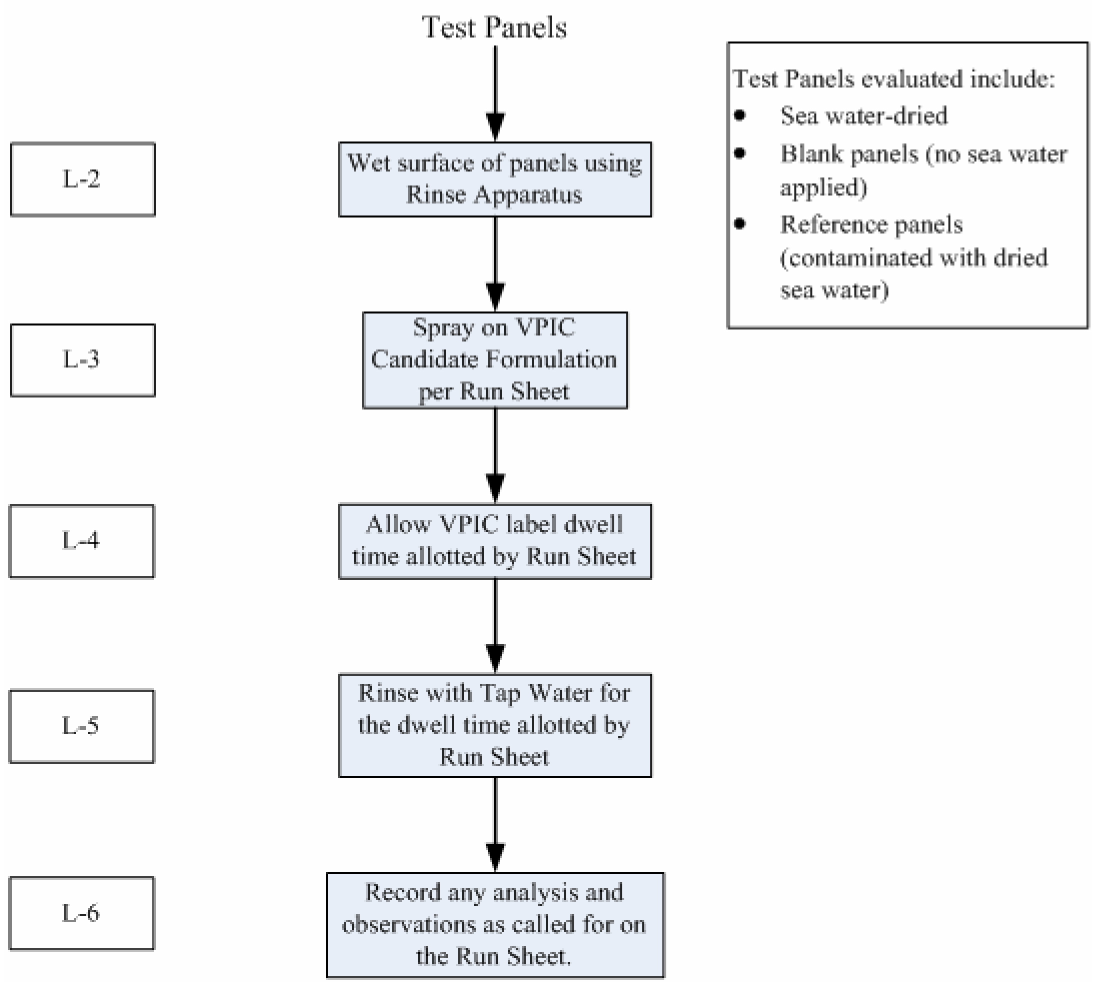
This protocol is provided as Flow Scheme 2.

Scheme 2:

VCPI MONITORING OF CLEANING STEP FOR NAVY EXTERIOR SURFACES PRIOR TO APPLICATION OF PRIMER AND TOP COAT

Laboratory Pre-Test Screening Protocol

<u>Step #</u> <u>Process Step Description</u> <u>Notes</u>



Appendix D
Pre-demonstration Trials and Results

REPORT OF OFFICIAL TRAVEL

DATE: 17 February 2006

BY: Nick Conkle and Kevin Rose

LOCATION: Hill AFB, Layton UT

PARTICIPANTS:

Government

- Richard Buchi, 309th MXSG/MXRL, Science and Technology Lab, Test POC 801-775-2993
- Wayne Patterson, 309th MXSG/MXRL Science and Technology Lab, Material Engineer, 801-775-2992
- Richard Dorber, A-10 Paint Shop, 801-776-0879
- 1st Lieutenant Gary Roos, corrosion and painting representative to the A-10 SPO 801-776-3257
- Ashley Tanner, A-10 painter, 801-728-0649
- Justin Bettridge, A-10 painter, 801-728-0649

Battelle

- Kevin Rose, 614-424-7111
- Nick Conkle, 614-424-5616

SCOPE: To conduct a series of preliminary Dem/Val tests for the Visual Cleaning Performance Indicator (VCPI) technology on representative aircraft test panels. Testing would include applying a single VCPI formulation to the surfaces of bare and coated panels that were pre-soiled with various hydrophobic contaminants, and then validating contaminant labeling and detection, as well as cleaning efficiency. The results and conclusions collected from the subject test would be used to determine if a full-scale Dem/Val test will be completed on the lower surfaces of wings and fuselage of a single A-10 aircraft.

SUMMARY: The following information serves an as abbreviated summary of the daily activities completed during the visit to Hill AFB, UT. More detailed information is contained within other sections of the report.

15 Feb 2006: Kevin Rose and Nick Conkle met with the Hill AFB staff, traveled to the test site, and cleaned two panels stripped with plastic media blasting (PMB). These panels were then taped to divide the panels into test segments and each area was separately contaminated with lube oil, hydraulic oil, grease, and PreKote®. The basic test plan was followed, but the scope was expanded to assess VCPI tagging of contaminated surfaces after pole-scrubbing and power-scrubbing using PreKote®. To facilitate this test, a second set of PMB stripped panels were prepared and contaminated.

16 February 2006: Testing was performed showing that the contaminants could be labeled, that PreKote® pole scrubbing was equally as effective as power scrubbing in removing surface contaminants, and that the Air Force formulated VCPI solution did not stain painted surfaces.

CONCLUSIONS AND COMMENTS: Based on the preliminary Dem/Val test observations, the following conclusions were drawn. Corrective actions in response to AF comments are provided too (see text in italics).

1. The Air Force VCPI solution did successfully label lubricating oil, grease, PreKote residues, as well as glue and tape residues. This same solution did NOT stain a MIL-PRF-85285 approved ELT or APC topcoat.
2. The VCPI solution failed to label hydraulic fluid as effectively in this field pretest as was demonstrated in the laboratory*. Efforts will be initiated by Battelle to adjust concentrations of dye and carrier agent in AF VCPI solution, as well as examine test panel surface finish and water rinsing method. Battelle believes that observed field results were influenced by (1) concentration of isopropyl alcohol (IPA) in solution, (2) surface finish of panels, and (3) water rinse (stand-off distance and impingement speed/direction).*
3. Many of the government participants expected the VCPI dye to be incorporated into PreKote® and not as a stand-alone cleaning effectiveness step. *The proposed full-scale Dem/Val test on the A-10 aircraft was designed to use VCPI as a quality control tool for validating surface cleanliness prior to and after the alkaline wash and 1st PreKote application.* ***VCPI has been added to undyed version of B&B Tritech's ReGel®, but not PreKote®****. Pantheon Chemical has discussed option of adding VCPI to PreKote® as a means of verifying application density, uniformity, and distribution across airframe surfaces, but that is not part of this project.*
4. Air Force representatives commented that current VCPI spray application methods are too slow. *Battelle plans to use a more efficient and faster spray application method for full-scale Dem/Val test.*
5. Battelle perceived a mixed interest level and decision to proceed with full-scale Dem/Val test. *Preliminary Dem/Val tests on A-frame panels confirmed that VCPI is capable of labeling surface contaminants, with minimal risks to aircraft structures. Full-scale Dem/Val test on A-10 aircraft structures are not intended to add an additional step to current cleaning operation, and must be recognized as a means of identifying viability of technology for production QC assessments.*

DETAIL DISCUSSIONS:

***15 February 2006*:**

Inspection: Battelle representatives met with Dick Buchi, loaded processing equipment into a GOV truck, and drove to Building 220. We entered an empty F-16 painting bay where two A-frames were set up. Wayne Patterson joined the group, and we inspected the two 4-ft x 12-ft PBM-stripped aluminum panels (Al 2024 or 7076 T6) and the two 4-ft x 12-ft Advanced Performance Coating (APC) painted panels; see Figures D1 and D2.

Figure D1. Two A-Frames of Stripped and Painted Panels In F-16 Painting Bay

Figure D2. PBM-Stripped Panels on A-Frame

We inspected and found the PBM-stripped panel to have a rough surface and some residual dust. On the front stripped panel some residual glue and small streaks of black/gray primers were present. The two APC painted panels were inspected. One was rough with overspray, but the other had a finer, smoother surface more characteristic of an aircraft surface, and it was selected for use.

Pre Cleaning: the following steps were performed to prepare the pair of stripped panels for testing. (No actions were performed on the painted panels.)

1. The panels were rinsed with water (~30 seconds).
2. 50% solution of B&B Tritech's ReGel® alkaline cleaner was sprayed on the surface and scrubbed in with Scotch Brite pads (< 1 minute). See Figures D3 and D4.

Figure D3. ReGel® Being Sprayed on Stripped Panels

Figure D4. ReGel® Scrubbing

3. The surface was then rinsed with water (< 1 minute). See Figure D5.

Figure D5. ReGel® Rinsed Off

4. The surfaces were dried using compressed air (~1 minute).
5. The surface was power sanded using 180 grit 3M pads (2 to 3 minutes). See Figure D6.

Figure D6. Surface Power Scrubbed Using Pneumatic Tools

6. The surfaces were inspected. The front (near side) panel, designated the "A" panel, still had residual glue and primer; see Figure D7. This was removed using MEK, see Figure D8.

Figure D7. Cleaned Panel Showing Paint and Glue Residues

Figure D8. Residual Paint and Glue Being Removed by Hand Using MEK

7. The surface of the “A” panel was rinsed with water (<1 minute).
8. The two panels were allowed to air dry (~15 minutes).
9. The surfaces were hand dried with towels (~1 minute).
10. A strip of 2-in.-wide silver tape was added horizontally about midway up the 4-ft height of the “A” panel. It was subsequently divided into 6 vertical segments using more silver tape; see Figure D9.

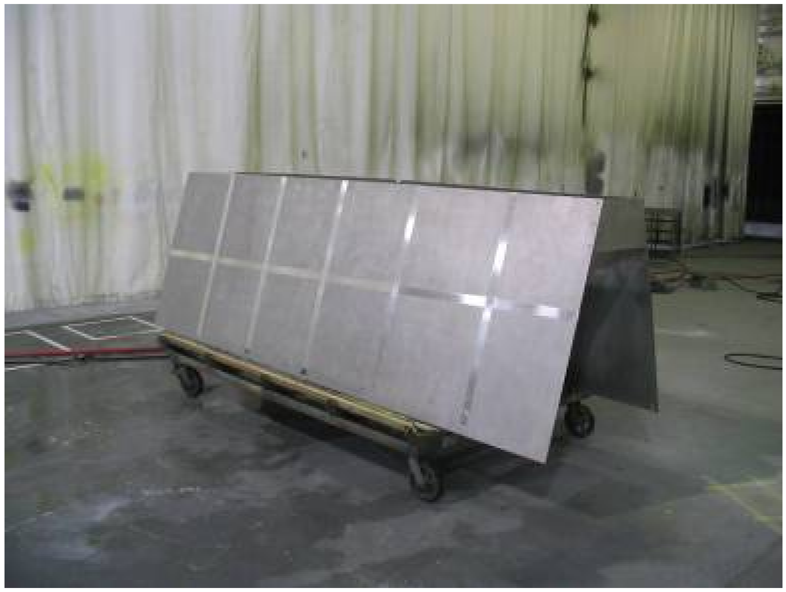


Figure D9. "A" Panel (Front) Divided Into Six Vertical Sections

11. A similar procedure was followed on the "B" (rear) panel. Except the horizontal line was raised higher on the panel, and the 12-ft long sheet was divided into 8 vertical segments; see Figure D10.

Figure D10. "B" Panel (Rear) Divided Into Eight Vertical Sections

Contaminant Addition:

12. The six vertical segments of the 'A" panel, were designated A-1 through A-6.
13. Segments A-2, -3, -4, and -5 were contaminated by rubbing on lube oil, hydraulic oil, or grease using a towel, or spraying on PreKote®; respectively. See Figure D11.


Figure D11. Hand Applying Contaminates
(Grease in this photo)

14. PreKote® was sprayed on and allowed to dry. See Figures D12 and D13.


Figure D12. PreKote® Being Sprayed onto Surface

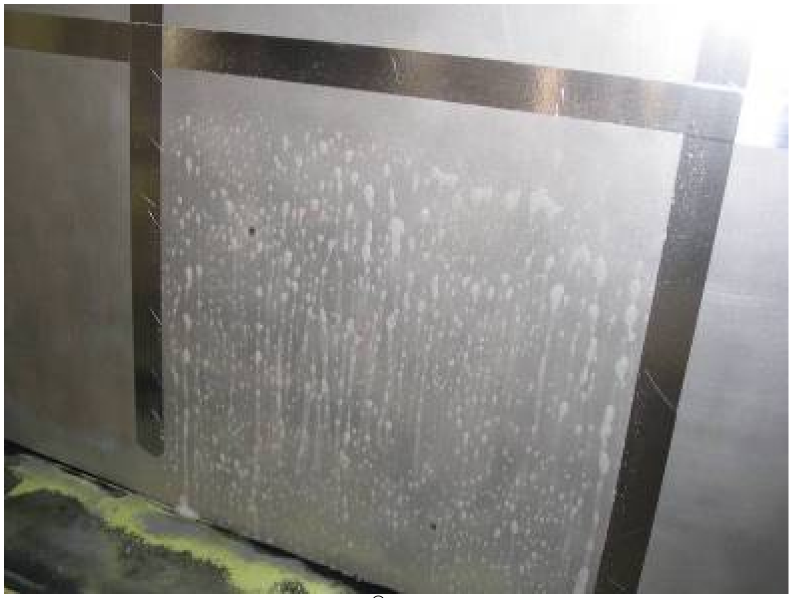


Figure D13. PreKote® Contaminated Segment

15. A similar procedure was followed on the "B" panel.
16. The contaminants on the panels were allowed to air dry until the following day.
17. A summary of the contaminants by segment is noted below.

Contaminant	"A" Side	"B" Side
No-Contaminants Control(a)	A-1, -6	None
Lube oil	A-2	B-1, -2
Hydraulic oil	A-3	B-3, -4
Grease	A-4	B-5, -6
PreKote®	A-5	B-7, -8

(a) Note: the top portion of each segment was left uncontaminated.

***16 February 2006*:**

VCPI Tagging of Contaminates: Battelle representatives returned to Building 220. The fluids had been on the surface of the panels for ~22 hours. The following procedure was used to test for labeling.

1. The VCPI solution was prepared by mixing in a 5-gal pail with a drill-motor mixer. The solution was then pouring in a 1-quart can of an air-atomized spray system; see Figure D14.

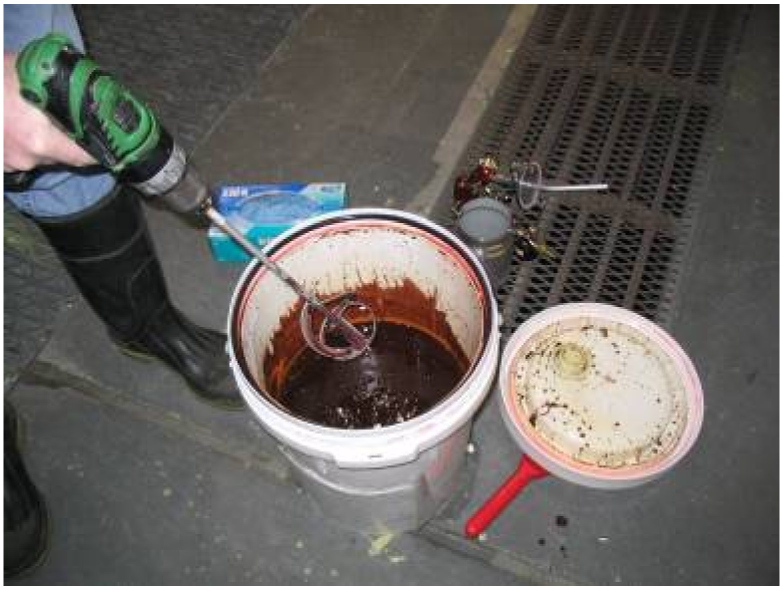


Figure D14. VCPI Solution Mixed and Ready for Use Along with 1-Quart Paint Can and Spray Head

2. The “A” panel was rinsed with water; see Figure D15.

Figure D15. “A” Panel Being Rinsed Prior to VCPI Coating

3. The VCPI solution was applied using an air-atomized HVLP paint gun. Initially the rate was very low. The painter suggested an adjustment to provide a cone pattern that allowed a greater VCPI-solution application rate; see Figure D16.

Figure D16. VCPI Solution Being Applied to Panel

4. The VCPI solution was allowed to stand on the surface of the panel for approximately 30 seconds after the last segment of the panel was coated.
5. The VCPI solution was then rinsed off; see Figure D17.

Figure D17. VCPI Solution Being Rinsed from Panel "A"

6. The panel and each segment were then inspected; see Figure D18. The control areas, and the PreKote®-labeled area, A-5, showed no labeling. The lube oil-labeled area in segment A-2 was strongly colored. The grease-labeled area in segment A-4 was also readily detected. The hydraulic fluid-labeled area in segment A-3 was only slightly colored. A portion of the silver tape used to separate the segments was removed. A very pale pink coloration of VCPI-labeled hydraulic fluid contaminated area can be seen below the area where the tape was placed. See Figure D19A.

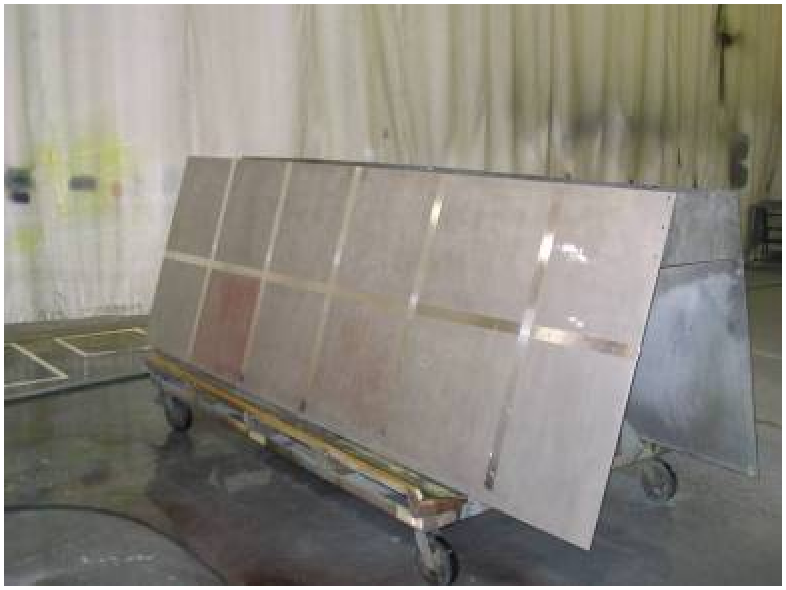


Figure D18. Panel After Rinsing
(Top and Segments A-1 and A-6 are Controls.
Segments A-2: Lube Oil, A-3: Hydraulic Fluid;
A-4: Grease; A-5: PreKote®

Figure D19A. Close up of VCPI-Labeled Hydraulic Fluid on Segment A-3

7. Small areas on the panel were brightly colored. Upon closer inspection these were identified as glue from the masking tape that had not been removed in the MEK wipe; see Figure D19B. The ability to identify the glue contamination was view as a positive added benefit.

Figure D19B. Glue Colored by VCPI Solution

8. Because hydraulic-fluid-contamination detection was a high priority with the base, a control surface was contaminated with a Hill AFB sample of hydraulic fluid, sprayed with VCPI solution, allowed to dwell, and rinse. The same minimal labeling was again observed.
9. The following VCPI-labeling observations were made.

Contaminant (and Segment)	**Label Observed**	**Impact on the Acceptance of VCPI**
Lube Oil (A-2)	Was labeled	Good
Hydraulic Oil (A-3)	Barely labeled	Bad
Grease (A-4)	Was label strongly	Good
PreKote® (A-5)	Minimal labeling	Good
Controls with uncontaminated surfaces (top of each segment and A-1 and A-6)	Minimal labeling	Good

Observation of the Contaminated Surfaces after Pole Scrubbing and Power Scrubbing Applications of PreKote®: on February 15th the rear ("B") 4-ft x 12-ft PBM-stripped aluminum panel was divided into eight segments, contaminated, and allowed to sit. On the 16th we followed the procedure noted below to assess scrubbing technique effectiveness.

10. The "B" panel was rinsed.
11. Next, to ensure that PreKote® could remove VCPI solution, the panel was sprayed with VCPI solution; see Figure D20.

Figure D20. VCPI Solution Being Applied to the “B” Panel

12. The VCPI solution was allowed to dwell for 30 seconds; see Figure D21. The panel was then rinsed; see Figure D22.

Figure D21. Panel “B” After VCPI Solution Addition

Figure D22. Panel "B" As the VCPI Solution Was Rinsed Off

13. We observed the same labeling effectiveness as noted for the "A" panel discussed above.
14. The VCPI-treated panel was then sprayed with PreKote® see Figure D23.

Figure D23. PreKote® Solution Being Sprayed Onto the "B" Panel

15. The PreKote® was scrubbed in using the pole scrub and a power scrub procedures for each contaminated segment; see Figure D24. (For example, segments B-1 and -2 were contaminated with lube oil. B-1 was pole scrubbed. B-2 was power scrubbed.) It was then rinsed.


Figure D24. PreKote® Being Scrubbed into Each Segment

16. The findings are noted below.

Test	Impact on the Acceptance of VCPI
Pre Kote® readily removed the VCPI solution	Good
Pole scrub (4 second scrub time for a 1.5-ft x 3-ft segment) versus power scrub (9 seconds) gave similar results in terms of cleaning effectiveness	Information only. (There is no interest in eliminating the power scrub application method.)
Standard duration PreKote® scrubbing did not remove all of the lube oil and all of the grease. A slight pink VCPI color remained	Good
Standard duration PreKote® scrubbing completely removed the hydraulic fluid	Neutral

17. Standard duration PreKote® scrubbing did not remove all of the lube oil (segments B-1 and -2) nor all of the grease (B-4 and -5). It completely removed the residual hydraulic fluid and PreKote®. A slight pink VCPI color remained on B-1 and -2 and B-4 and -5; see Figure D25.

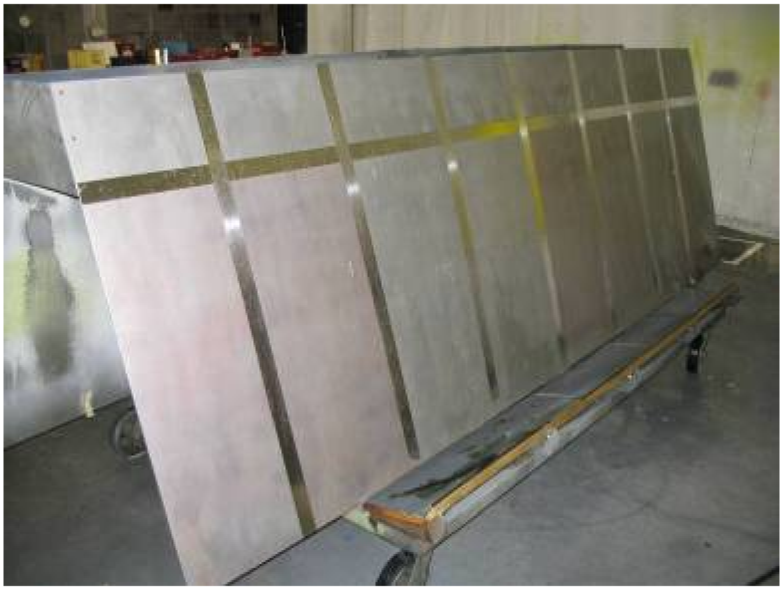


Figure D25. VCPI-Label Indicated the Lube oil and Grease Contaminated Segments had Not Been Completely Cleaned

18. The entire panel was re-power scrubbed (17 seconds per segment). This removed all color from the VCPI labeling; see Figure D26.

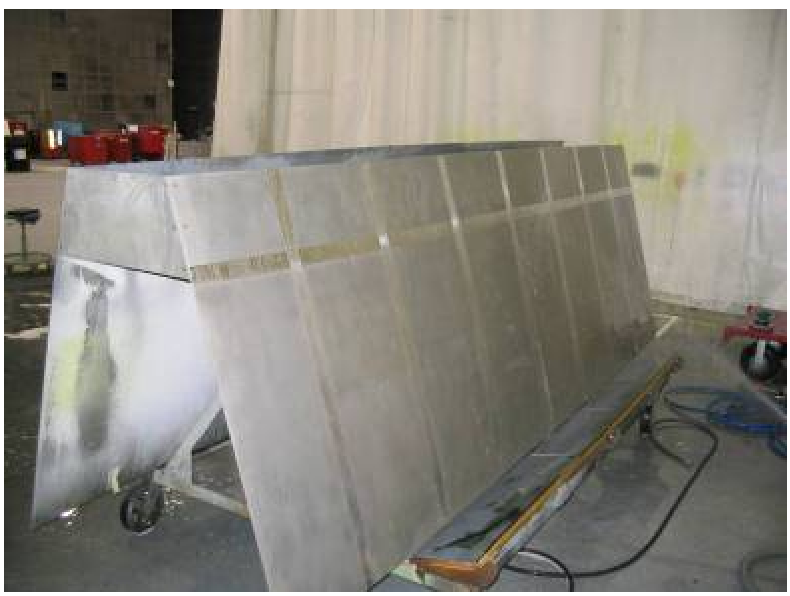


Figure D26. Panel Shows No VCPI Label after Extended Power Scrub, but Surface Still Contaminated
(Water is being sprayed on the surface to check for water break)

19. The solution was re-sprayed with VCPI solution and rinsed. The VCPI solution did not appear to label these residual contaminants. But upon closer inspection and water break testing, it was observed that the VCPI solution achieved some cleaning on its own. After VCPI application and rinsing, the formerly contaminated surface was water break free!

VCPI Solution Adhesion and Coloring of APC-Painted Surfaces: the painted surface was testing to confirm that VCPI would not stain the primered or painted surfaces. The following steps were followed:

20. The surface of the APC panel was sprayed with water.
21. VCPI solution was applied to the center of the panel; see Figure D27.

Figure D27. VCPI Solution Applied to the APC Painted Panel

22. It was rinsed with water and no residual coloration or staining was observed; see Figure D28.

Figure D28. Painted Panel after Water Rinse

23. There was a question if VCPI could detect contaminants on painted panels. To test, Hill AFB hydraulic fluid was rubbed on to the panel, and the fluid was allowed to drip onto the surface and then VCPI sprayed on. As noted in Figure D29 the areas with hydraulic-fluid contamination was readily detected.

Figure D29. Painted Panel after Hydraulic Fluid Used To Contaminate the Surface and VCPI Solution Sprayed On

24. The solution was then sprayed with water. Under a gentle spray the areas which were contaminated with hydraulic fluid could be easily detected; see Figure D30.

Figure D30. Hydraulic Fluid-Contaminated on Painted Surface After Gentle Spray

25. However, if rinsed with enough water the visual evidence of the hydraulic fluid contamination could be removed; see Figure D31. The panel was not clean, and if you ran your hands along the surface it would leave red streaks of red hydraulic oil and red VCPI solution. If wiped with a towel, it turned the towel red. This is different than spraying VCPI on a clean panel, spraying with VCPI solution, and rinsing; as noted in Figure D28, the VCPI labeling and rinse operation left the surface contaminant free.

Figure D31. Hydraulic Fluid-Contaminated Pained Surface After Extended Water Rinse

26. The rubber border that the panels sit on showed some discoloring. But this was tested and the staining was found from a pre-existing condition and not connected to VCPI.
27. The following paint staining findings were made.

Test	Impact on the Acceptance of VCPI
VCPI did not stain the primer or painted surfaces	Good
Painted surfaces contaminated with hydraulic fluid were strongly labeled by VCPI	Good
VCPI did not stain the paint on the rubber support pad	Good
VCPI appeared to do some additional cleaning of the surface over and beyond that of isopropanol	Good

General Comments:

1. Workers like PreKote® because it allows them to avoid the acid brightening step and dealing with toxic chromium.
2. Hill AFB pre-treats A-10, F-16, and C-130s using PreKote®.
3. They are not authorized to use PreKote® for Navy or Army C-130s. In all cases they use a chromated primer. The official reason for naval rejection of PreKote® is that it has not been validated in the more several environments that Navy aircraft are subjected to.
4. Only the three-step, power-scrub PreKote® application route is approved at Hill AFB.
5. Other, less stringent procedures are used at other bases and in the commercial market.

6. There is a belief that the PreKote® is not applied consistently, and may vary by day and by shift. Therefore it is important that the three-step process with power-scrub be retained to compensate for these perceived deficiencies in the application of PreKote®.
7. Before PreKote® was adopted, there were 4 or 5 aircraft retuned each year for repainting because of poor surface preparation. Since PreKote® has been implemented, this number has dropped to zero.
8. It is widely believed in the military that a chromated coating, either in the pre-treatment or in the primer, is needed to ensure adequate corrosion protection.
9. Dick Buchi believes that the chromated primer route provides the most effective protection procedure.
10. Original equipment Manufacturers (OEM) like Boeing buy their aircraft-skin panels pre-treated and primered. They have out-sourced all these high-contamination chromium-application steps. They do need to do some touch up sanding, so they prefer to use a chromated pre-coat and a non-chromated primer, so dust from sanding will not liberate chromium-contaminated dust.
11. Robins AFB does not use PreKote®. They believe that a chromated pre-coat and a non-chromated primer is the preferred route.

ACTION ITEMS:

The following action items were identified:

1. Investigate alternative VCPI formulations to determine if the visual labeling of hydraulic fluid can be enhanced. Options that could be considered include:
    a. Different concentration of Oil-Red-O dye
    b. Different concentration of IPA
2. Find a faster way to apply the VCPI solution (such as using an airless applicator similar to the system used to apply the B&B Tritech's ReGel®, PreKote®, primer, and APC at a rate of many gallons per minute.)

Appendix E
Data Quality Assurance/Quality Control Plan

E.1 Purpose and Scope of Plan

This plan is designed to delineate the approach for monitoring and demonstration to ensure that facilities, equipment, personnel, methods, practices, records and controls are in conformance with the ESTCP-approved data quality objectives. The plan outlines and delineates personnel responsibilities and expectations.

E.2 Quality Assurance Responsibilities

To best implement this plan, certain roles and responsibilities are necessary to insure that the program's data is properly generated, catalogued and retained. The following table outlines the roles and responsibilities of key personnel working on this program:

Role	Responsibility
QA Officer/Project Manager John Stropki – Battelle	Ensures data quality and ensures that the facilities, equipment, personnel, methods, practices, records, and controls are in conformance with ESTCP-approved data quality objectives
Laboratory Manager Dr. Bruce Monzyk – Battelle	Ensures the proper collection, storage, and retention of laboratory-generated data
Field Team Leader Kevin Rose – Battelle	Ensures the proper generation, collection, storage, and retention of field-generated data
Data Processor *Not Used*	N/A
Modeler *Not Used*	N/A
Data Reviewers Anne-Claire Christiaen - Battelle Richard Buchi – OOALC (309 MXSG/MXRL)	Ensures accuracy and completeness of data collection and retention
Essential Subcontractor and Support Personnel Robert Russell - Battelle	Generates laboratory data

E.3 Data Quality Parameters

The Team will follow generally accepted practices for generating and collecting laboratory data during the preliminary, bench-scale testing phase. Battelle's accredited laboratory is registered to ISO 9001:2000 and is accredited to ISO 17025.

Field data will be collected under the supervision of an experienced Field Team Leader with over 15 years of experienced in the collection and analysis of quality field data. The primary stakeholders and production-level supervisors from the Navy and Air Force will also ensure accurate data collection and analysis.

All data will be reviewed by the Government Program Manager and selected Battelle management staff, including staff dispatched to the demonstration/validation site to oversee data collection and ensure the completeness, comparability, accuracy, and precision of the data.

E.4 Calibration Procedures, Quality Control Checks, and Corrective Action

Battelle's Advanced Materials Processing and Characterization Laboratories are registered to ISO 9001:2000, an international quality management standard. Technicians and service personnel within each of these groups follow testing processes and data analysis procedures explained in a quality manual and laboratory-specific standard operating procedures. The quality management system undergoes periodic internal audits and management reviews. Additionally, these labs have been accredited to ISO 17025, an international quality standard that specifies general requirements for the competence of testing and/or calibration laboratories.

The procedures put in place to attain and maintain these accreditations ensure that calibration procedures, quality control checks, and corrective actions are compliant with the state of the art in QA/QC.

E.5 Demonstration Procedures

Because this project deals with the qualification of experimental compounds formulated from commercial-off-the-shelf chemicals for the detection of large area contaminants, it is not anticipated that any problems concerning technology startup and/or maintenance will be encountered. The "technologies" (in this case, dye-solvent combinations), do not have significant issues concerning storage (shelf life) or use, which would be the only problems which might arise in this area.

E.6 Calculation of Data Quality Indicators

Due to the qualitative nature of the demonstration procedure, this section is not applicable to this program.

E.7 Performance and System Audits

Because of the nature of this program's demonstration procedures, performance and system audits are not applicable to this program.

Because of the broad range of services and facilities available at Battelle, in addition to support from Air Force Research Laboratories, a contingency laboratory is not anticipated for this program.

E.8 Quality Assurance Reports

Status reports will be generated commensurate with ESTCP required reporting. As previously discussed, audit reports are not applicable to this program.

E.9 ISO 14001

Due to the qualitative nature of the demonstration procedure, the requirements specified for this environmental management standard is not applicable to this program.

E.10 Data Format

Data collected will be logged in a permanent laboratory or field notebook maintained by the individual collecting the data. This data shall be recorded directly, promptly, and legibly in ink. All data entries and photographs documenting the Dem/Val tests shall be dated on the day of entry and signed or initialed by the individual recording the data. Any change or amendment of entries shall be recorded separately from the original entry, leaving the original entry intact. All changes will be signed or initialed by the individual making the change, and the reason for the amendment.

Any unforeseen circumstances that may affect the integrity of the demonstration will be noted. In the case of this program, environmental conditions (e.g., temperature, atmospheric conditions) will be noted. All deviations from standard practice or changes in ambient conditions will be noted, protecting the integrity of the data.

E.11 Data Storage and Archiving Procedures

Battelle has established and maintains procedures for the identification, collection, indexing, filing, storage and maintenance of data. All data are stored and maintained in electronic format so that they are readily retrievable. If required by the contract, the data shall be provided to the client.

Data and documentation will be maintained at Battelle, archived for a minimum of four (4) years, and then discarded when no longer used or needed.